5.0 AIRCRAFT OPERATIONS

5.1 Overview

The aircraft that will participate in the experiment are described briefly in Table 5.1-1. More details for the aircraft and instruments are given below and in Appendix D.

Table 5.1-1. Aircraft Overview

Aircraft (Sponsor)	**Duration, hrs Range, nm**	**Altitude, ft**	**Base**	**Research Hours/ No. of Flights Flight Period**
NASA ER-2 (FIRE)	6.5 / 2600	60,000	Fairbanks (Wainwright)	50/10 Spring
NCAR C-130 (SHEBA)	10 / 2000 (B.L.) 3000 (20K')	100-28,000	Fairbanks (Wainwright)	90/10 Spring 70/8 Summer
UW Convair 580 (FIRE)	5-7.5/ 3000	100-25,000	Barrow	80/13 Spring
Canadian Convair 580 (FIRE)	5.5-8 / 800-1200	100-25,000	Inuvik	65/8 Spring
Quicksilver GT500 (SHEBA)	6/?	10,000	SHEBA Ship	300 Spring
Helicopter (SHEBA)	?/?	?	SHEBA Ship	twice weekly fights during summer
Twin Otter (SHEBA)	?/?	?	Prudhoe Bay SHEBA Ship	2 flights every 6 weeks; increase to every 3 weeks during Spring

5.2 Aircraft and Instrumentation Descriptions

5.2.1 NASA ER-2

The ER-2 is a single engine, single seat high altitude subsonic aircraft with a long history of successful science data collection missions. The aircraft has four main pressurized (approx. 2.5 psia) payload compartments(Nose, Q Bay aft of cockpit, and two wing pods) with standardized provisions for electrical power, data distribution, and cockpit control. Typical flight profile is max power climb to initial cruise altitude somewhere in mid 60K ft. range with cruise climb throughout flight to reach approx. 70K ft. at beginning of descent. Sortie duration is normally limited to 6.5 hours unless required science data cannot be obtained any other way other than a maximum range flight limited to 8 hours. Research instrumentation on board the aircraft and data products to be obtained are described in Appendix D, section D.2.

- Based at Fairbanks
- About ten flights
- Objectives are surface measurement validation, surface characterization and cloud characterization
- Spirals are good for microphysics and stair steps are good for turbulence and radiation

- Flies primarily from Fairbanks to/from Ship via Barrow(on one leg)
- Closely coordinated flights with U WA CV-580 for BDRF measurements
- Underflights to be over Ship and Barrow for clear and cloudy skies
- Intercomparison with C-130 over Ship every flight possible; minimum of 1 clear, 1 storm and 1 boundary layer
- Underfly Polar Orbiters as much as possible; AVHRR calibration
- LANDSAT coordination flight on May 21 and June 6
- May fly on two consecutive days
- Decide go/no-go based on Ship radar and MAS
- Ferry time from Dryden to Fairbanks is 10-11hrs.
- Round trip flight time from Fairbanks to the Ship at 75 N is 3 hrs. 45 min.

Table 5.2.1-1 Anticipated mission distribution for ER-2

Mission	**Frequency, # flights**
Clear conditions	1
B.L. liquid cloud	1
B.L. mixed phase	4
B.L. ice cloud	2
Overlapped clouds	2
C-130 intercomparison	8
Barrow	5
SHEBA Ship	10

5.2.2 UW CV-580

The University of Washington Convair 580 is a four-engine medium altitude research aircraft. A majority of its instruments make in situ measurements. The research instruments and their data products are listed in Appendix D, section D.3.

- Based at Barrow
- Objectives are cloud characterization, haze and surface measurement validation
- Flies mostly in coordination with ER-2
- About 13 flights
- Will take numerous opportunities to gather measurements over Barrow
- One intercomparison flight with C-130 over Ship
- Will have about 4 hours over the Ship on each flight to the Ship
- Decide go/no-go based on Ship radar, CAR on UW CV-580 and Ship wind direction
- May fly on two consecutive days
- Coordinate with satellites over Ship on every flight possible

Table 5.2.2-1 Anticipated mission distribution for UW CV-580

Mission	Frequency(%)*
Clear Conditions	5
BDRF surface	10
BDRF clouds	10
B.L. liquid clouds	5
B. L. mixed phase clouds	15
B. L. ice clouds	5
Overlapped clouds	10
Barrow	20
SHEBA Ship	20

* The percentage frequency is a measure of the research emphasis. Eighty research hours spread over about 13 flights is anticipated. Several missions should generally be accomplished on each flight, and any of the first seven flights might, at various times, be carried out over the Barrow or SHEBA sites.

5.2.3 NCAR C-130Q

The NCAR C-130 is a four-engine medium altitude research aircraft. A majority of its research instruments make in situ measurements. Its research instruments and their data products are listed in Appendix D, section D.2.

- Based at Fairbanks
- Objectives are cloud characterization, surface measurement validation and leads
- Looking for clear, cloudy and stormy weather over Ship
- About 10 flights in Phase I and 8 flights in Phase II
- Flies primarily to/from Ship(will gather Barrow measurements as Ship location permits during small detour or overflight)
- Intercomparison with ER-2 over Ship on every possible flight
- One clear, one storm and one boundary layer minimum intercomparison with ER-2
- Intercomparison with U WA CV-580 over Ship one time
- Intercomparison with Canadian CV-580 one time over Ship when clear
- Coordinate with Satellites over Ship on every flight possible
- Will not fly on two consecutive days
- Decide go/no-go based on Ship radar, two major instruments on C-130 and Ship wind direction

Table 5.2.3-1 Anticipated mission distribution for NCAR C-130 (Phase I and II)

Mission	Frequency Phase I*	Frequency Phase II*
Clear stable B.L.	1	1
Surface mapping	6	6
Leads	2	
liquid cloudy B.L.		3
mixed cloudy B.L.	3	2
ice cloudy B.L.	3	
broken B.L. clouds		2
cirrus and altostratus	2	2
multi-level clouds	1	3
Barrow	1	1
SHEBA Ship	8	6

* based on number of flights

5.2.4 Canadian CV-580

The Canadian Convair 580 airplane is a four-engine medium altitude research airplane. Its research instruments make both remote and in situ measurements. Its research instruments and their data products are listed in Appendix D, section D.4.

- Based at Inuvik; refuel at Prudhoe Bay or Barrow
- Objectives are cloud characterization, leads and haze
- Flies primarily from Prudhoe Bay to/from Ship
- Flies mostly in coordination with the Ultralight
- About 8 flights
- May detour over Barrow on one flight when flying from Prudhoe Bay
- Will gather considerable measurements over Barrow when flying from there
- Coordinate with DMSP and POES over Ship on every possible flight
- Intercomparison flight with C-130 over Ship during clear conditions, if possible
- May fly on two consecutive days
- Decide go/no-go based on Ultralight availability and Ship wind direction

Table 5.2.4-1. Anticipated mission distribution for Canadian Convair

Mission	Frequency, %
Leads/Fluxes	14
Clouds	25
Arctic “haze”, aerosol, chemistry	25
SHEBA Ship/Arm Comparisons	30
Satellite Comparison	6
C-130 Comparison	??

Table 5.2.4-2 Frequency of Area Coverage

Area	No. Flights	Hours	Percent
Over Sea off Inuvik	8	31	48
SHEBA Ship	4	18	27
Inuvik-Barrow-Inuvik	8	16	25

Table 5.2.4-3 Flight Condition Preference

Platform/ Instruments	30km legs	>60km legs	Spirals	L box
Aerosols/ Chemistry		√		√
Radiative Fluxes		√		√
Lidar		√		
Heat/Moisture Fluxes/Dynamics	√	√	√	√
Satellite		√		√
Microphysics	√		√	√

5.2.5 NOAA Quicksilver GT500 "ULTRALIGHT"

A single-engine research airplane. Its research instruments and their data products are listed in Appendix D, section D.5.

- Based at the SHEBA Ship
- Objectives are cloud characterization, leads and surface characterization
- Flies only around the Ship
- surface fluxes in clear skies; as low as 5m above surface
- fly under the C-130 looking for leads and turbulence associated with them
- Close flight coordination with Canadian CV-580 for all CV-580 flights
- One intercomparison flight with C-130

5.2.6 SHEBA Twin Otter

- for transportation of personnel to/from Ship

5.2.7 SHEBA Helicopter

- for polar bear and sea ice studies
- operate every 3-4 days from June through October 1998
- performs 20km transects every 1-2km

The aircraft funded by SHEBA will place first priority on the following SHEBA objectives:

- produce statistics of the surface and characteristics on 10 km scales, melt pond fraction and size distribution (possibly depth distribution), lead width distribution (including open water/new ice fractions), surface albedo, surface temperature as a function of surface type, components of the surface radiation flux, cloud fraction, mean optical depth and its variance mean and variance of liquid water content and particle size/phase;
- testing of different theories for "scaling up" from point measurements to an area average measurement of fetch-dependent turbulent fluxes across leads and testing theories for the surface turbulent flux from leads;
- measurement of surface fluxes over ridges to test theories for the local fluxes;
- investigation of the surface fluxes downwind of leads and ridges and how they are influenced by the lead and ridge characteristics;
- investigation of snow-depth variability and its influence on surface roughness and turbulent fluxes;
- investigation of the impact of variations in melt pond spatial coverage and depth distribution on the local reflectance and aggregate-scale albedo;
- determination of relationships between melt pond characteristics and ice type;
- documentation of the relationships between coarse-scale, areally-integrated observations and local-scale measurements of surface albedo, temperature, and fluxes to determine errors introduced by sampling at different spatial and temporal resolutions.

5.3 Flight Planning Strategy

In support of the FIRE scientific objectives, the programmatic goals of the aircraft program are:

- provision of in situ data for the evaluation of ground-based, satellite and aircraft remote sensing instruments
- provision of data for radiative transfer modeling, single-column modeling, and boundary layer modeling activities
- characterization of surface physical characteristics, albedo, temperature, and surface fluxes on scales of tens of km
- characterization of 3-D structure of clouds on scales of tens of km
- characterization of atmospheric composition, vertical structure and radiative fluxes
- characterization of the atmospheric cloudy boundary layer (cloud, aerosol, radiation, state, and turbulent fluxes)

Table 5.3-1 summarizes how the objectives relate the capabilities of the aircraft.

Table 5.3-1 FIRE Objectives Relationship to Aircraft Capabilities

Objectives	Airplanes				
	Canadian CV-580	U WA CV-580	C-130	ER-2	Ultra Light
Clear conditions	√	√	√	√	
Cloudy boundary layer	√		√		
Leads	√		√		√
Surface sensor measurement validation with aircraft	√	√	√	√	√
Aircraft/satellite measurement intercomparison				√	
Arctic Haze	√	√			
Cloud Microphysics and radiation characterization	√	√	√	√	
Surface characterization and mapping			√	√	√

For some aircraft, the ferry flights will entail several hours between their base of operation and the SHEBA Ship. These flights provide opportunities to address aspects of the Project's science questions. Are there interesting features enroute to the Ship that could be flown over, such as lakes, extensive rivers(Yukon), or industrial pollution sources? The Yukon River is a big target, and the C-130 will fly over it enroute to the Ship. Ice breakup on the river occurs in early May and will be observed by the aircraft. Is there a particular flight track or altitude that would make the data derived from this event most useful? Ferry flight plans should be designed accordingly. Ferry flights could provide opportunities for aircraft measurement intercomparisons(C-130 flies over Barrow enroute to the SHEBA Ship.

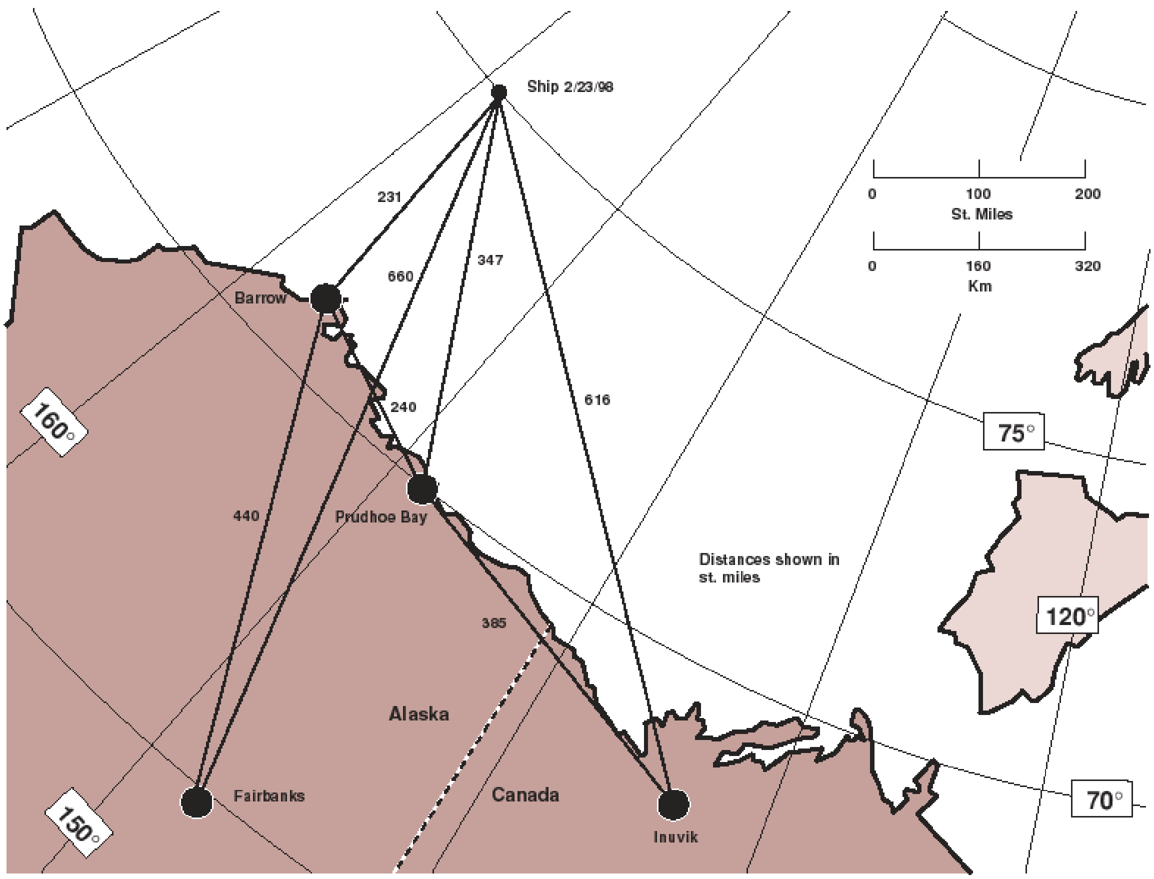
For example, with multiple layers of stratus clouds, the aircraft could obtain vertical and horizontal profiles by occasionally climbing above cloud top(when <30000 ft high), remaining there for 10-20 minutes, and then descending through cloud layers to the boundary layer. The "cost" of these maneuvers would probably be additional fuel, or less on-station time at the Ship, and could be estimated from aircraft performance specifications and likely wind profiles. Ascent and descent rates should be limited to about 1000 fpm, or less, in order to obtain adequate vertical resolution.

For baseline intercomparisons, there should be at least one successful overpass for all aircraft over theSheba Ship (required) and Barrow (desired) in clear sky conditions. These overpasses may be performed either with or without Polar Orbiter overflights. Aircraft flight plans should include loitering over the surface stations. Table 5.3-1 indicates aircraft speeds. Figure 5.3-1 indicates distances between the SHEBA Ship and the airplane bases of operations as of January 23, 1998.

Table 5.3-1 Aircraft Speeds

Aircraft	Cruise Speed, mph	Research Speed, mph	Ascent Rate, fpm	Descent Rate, fpm
Can CV-580	280	190	1000	1000
NCAR C-130	344		2000	2000
NASA ER-2	475		2000	2000
UW CV-580	326	185	1400-2000	300
Ultralight				

Figure 5.3-1 Distances between the Ship and Airplane Bases



Aircraft flights will be designed so as to maximize the chances of meeting all of the FIRE goals. In support of these goals, we anticipate the following distribution of flights among the project aircraft. It is noted that more than one objective may be accomplished on a single aircraft flight.

No single flight pattern will satisfy all of the goals, although some are general enough to satisfy several at once. Table 5.3-1 indicates the degree of compatibility between each goal and each of the others, for each of the aircraft. Goals ranked as highly compatible can both be completely satisfied by the same flight pattern and weather conditions. In general, a flight pattern dedicated to one goal will be considered to be dedicated to all other highly compatible secondary goals as well. Goals ranked as being of medium compatibility with the primary goal of a flight pattern may be satisfied as well if special care is taken and/or some adaptations made. Goals ranked as being of low compatibility with the primary goal are unlikely to be satisfied by the flight pattern type.

Table 5.3-1. Flight Pattern Compatibility

Science Issue Section 1.3	Flight Pattern (Section 5.4)												
	5.4.1	5.4.2	5.4.3	5.4.4	5.4.5	5.4.6	5.4.7	5.4.8	5.4.9	5.4.10	5.4.11	5.4.12	5.4.13
(1)													
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The following series of steps will be used to select aircraft flight pattern type for each flight day:

a. Weather forecasts, ice camp observations, and projections of available platforms and instruments will be used with Tables 4.2-4.4 (the aircraft operations table) to determine which of the unsatisfied goals are feasible.

b. Table 4.5 (the mission compatibility table) will be used to determine which of these goals is compatible with the greatest number of unsatisfied goals. This goal will be selected.

c. Taking into consideration the primary goal, the highly compatible secondary goals, and the available platforms and instruments, a general mission type and specific variant mission will be selected using the aircraft operations table.

d. If possible in light of the primary goal and highly compatible secondary goals, modifications will be made to the mission plan to enhance the satisfaction of the goals of medium compatibility. Meteorology, logistics, and satellite overpass times and orbits will be considered in selecting mission times.

e. The Surface Scientist(located at the SHEBA Ship) and the Aircraft Scientist and Daily Mission Scientist will have the option of modifying the daily flight mission on the fly if the atmospheric conditions at the Ship change substantially.

The degree of satisfaction of each goal will be ascertained after each mission. When a given goal has been satisfied by an adequate number of missions, it will be dropped from the list of unsatisfied goals used in the mission selection procedure above.

5.4 Flight Patterns

Emphasis will be placed on flying in the immediate vicinity (60 km) of either the SHEBA Ship or the Barrow ARM site. The only exceptions to this are Canadian Convair flights designed to examine leads and Arctic haze. All flights will be conducted during daylight hours. Some plans will have legs 20 km distance downwind of the site. Profiles over the site will incorporate either constant altitudes over the site(preferred), ramps, spirals, or circles at constant altitude. The plans should be about 1 hour in duration and be capable of being performed in cloudy conditions.

The NASA ER-2 will typically fly at an altitude of 20 km so that it can view the entire troposphere. The ER-2 will overfly the UW Convair 580 or the NCAR C-130 so that the ER-2 observations can be interpreted in the context of in situ aircraft measurements of cloud characteristics as well as surface observations. For the NASA-funded UW Convair 580 flighthours(39), emphasis will be placed on coordinated flights with the ER-2, when practical. The UW Convair will sample both boundary layer and upper-level clouds. The Canadian Convair 580 will fly alone most of the time (the exception being intercalibration with the C-130). All missions will be conducted in the cloudy boundary layer. The NCAR C-130 will fly some coordinated missions with the ER-2 and the Convairs. The C-130 will focus on the boundary layer, including mapping of the surface characteristics.

The flight plans must meet competing requirements of measuring horizontal variability and vertical structure. Horizontal traverses in the boundary layer will be 60 km in length, to insure a sufficient sampling length for turbulence and radiation. In some instances, including observations of upper level clouds or situations in low-level clouds where turbulence statistics are not needed, shorter traverses (10-20 km) will suffice. Horizontal traverses in the boundary layer will be made at a number of different levels within the boundary layer. Additionally, slow ascents and descents will be used to obtain continuous vertical profile. The boundary layer includes the surface layer and the Eckman layer, and extends from the surface up to the level of the geostrophic wind. For stable conditions in the Arctic, the boundary layer may be only 100m thick, and with convection, it could be up to 1000m thick.

If the SHEBA Ship continues its westward drift so that aircraft filghts need to take place west of 169 deg. West longitude, it will be necessary to secure permission from Russia for the group of flights and from Russian ATC prior to each individual flight. Each aircraft will pursue such permission through their own organization. NASA will contact the Russian authorities with background information on FIRE.ACE and note the other requests being initiated.

The flight patterns for each flight type are described below. Table 5.4-1 summarizes the flight patterns.

Table 5.4-1 Flight Pattern Summary

Section	**Name**	**Aircraft**	**Satellites**	**Time**
5.4.1	Cloudy Boundary Layer	C-130		3 hrs.
5.4.2	Clear Stable Boundary Layer	C-130; Ultralight		3 hrs.
5.4.3	Clear Sky	ER-2; C-130		
5.4.4	Leads	Can CV-580; C-130		
5.4.5	Surface Sensor Validation	ER-2; C-130; Can CV-580; U WA CV-580		
5.4.6	Surface Mapping	ER-2	yes	
5.4.7	Cloud/radiation	C-130		30 min.
5.4.8	Cloud Characterization	ER-2; U WA CV-580		
5.4.9	Arctic Haze	U WA CV-580; Can CV-580		
5.4.10	ER-2 coord. w/ U WA CV-580 and NCAR C-130	ER-2; C-130; U WA CV-580; Can CV-580	yes	
5.4.11	Aircraft /satellite intercomparisons	ER-2; C-130; Can CV-580; U WA CV-580	yes	
5.4.12	U WA CV-580/Surface Intercomparisons	U WA CV-580; Can CV-580		
5.4.13	SHEBA Aircraft	Ultralight, Helicopter; Twin Otter		

5.4.1 Cloudy Boundary Layer

Select case based on perceived mesoscale horizontal homogeneity. Select both solid (e.g. stratus) and broken (e.g. stratocumulus) decks. Select case without overlying clouds (i.e. no cirrus), although multiple boundary layer cloud decks are of substantial interest (particularly summer). Flight pattern should drift with the wind, so that approximately the same portion of the cloud continues to be sampled. Some portion of the sampling should be over a surface measurement site. At a single level, 120 km of measurements needed for turbulence statistics (if possible).

Levels sampled by horizontal traverses should be at least 150 m apart. One side of box or L-pattern should be in the along-wind direction

1. Horizontal leg of about 50 km over the site at the ferry level
2. Descend to surface to assess vertical structure and depth of the B.L.
3. Ascend to 1.5 km (or top of B.L., whichever is higher), fly box pattern with at least 40 km on a side
4. Descend to cloud top, fly horizontal leg of 40 km, skimming the cloud tops.
5. Descend into cloud about 100 m below top of highest turret so that you are always within cloud; at this level, fly L-pattern with 40 -60 km side; every 10 nmi (20 km) ascend to above cloud top and then descend back down to original flight level (porpoise)
6. Fly L-pattern with 40-60 km side at several levels within cloud
7. Descend to 30-90 m, fly box pattern with at least 40 km on a side
8. Fly horizontal L-pattern 40 km on side at selected levels between 200 m and the cloud base, with at least 150 m between levels (if two cloud layers are present, emphasize the upper cloud. Fly 1-2 L-patterns in lower cloud)
9. Ascent to above top of B.L.; descend to 90 m then ascend to above top of B.L. (profile)

** in potential icing situations, reduce length of in cloud legs in consultation with pilot

TIME: 3 hours [2 boxes, 6 L-patterns] (possibly times 2)

See figures 5.4.1-1 and 5.4.1-2 for flight patterns to be used by the C-130 and Canadian CV-580, respectively.

Figure 5.4.1-1a   C-130 Flight Pattern-Ground Track

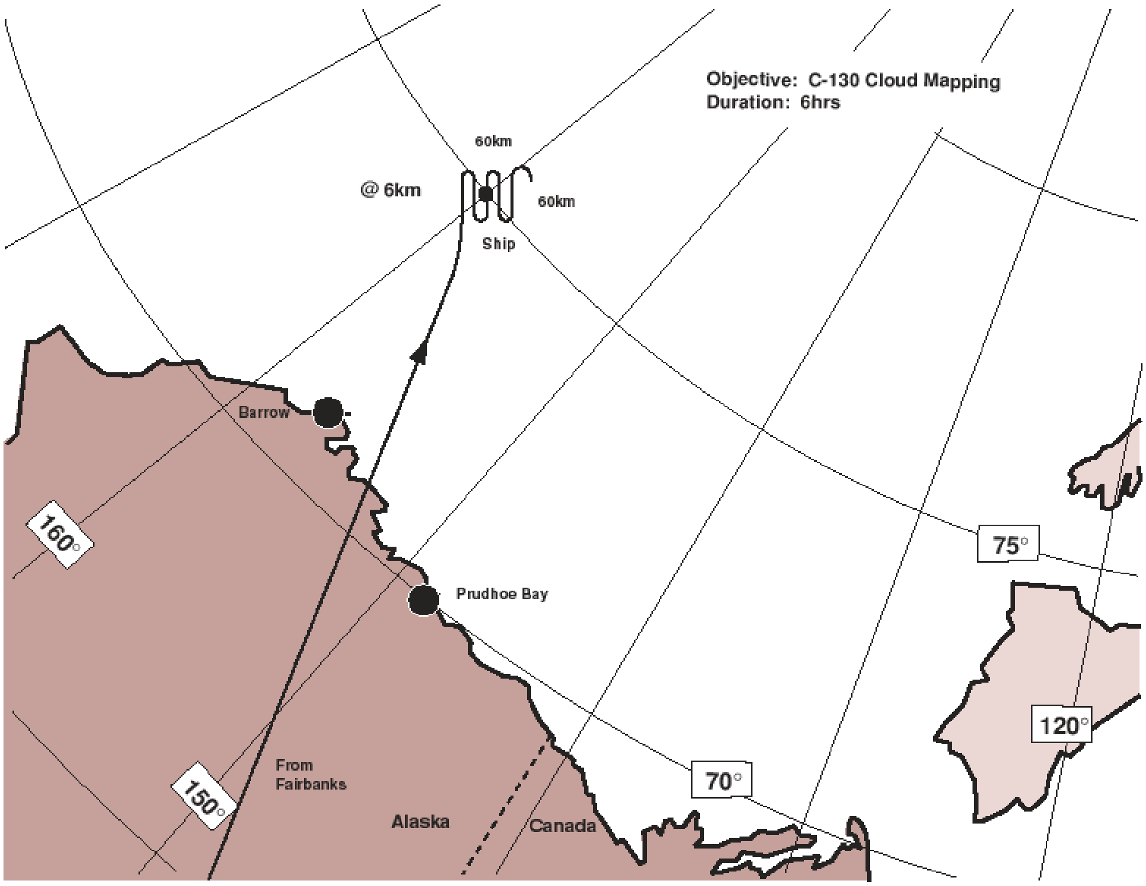


Figure 5.4.1-1b C-130 Flight Pattern-Ground Track

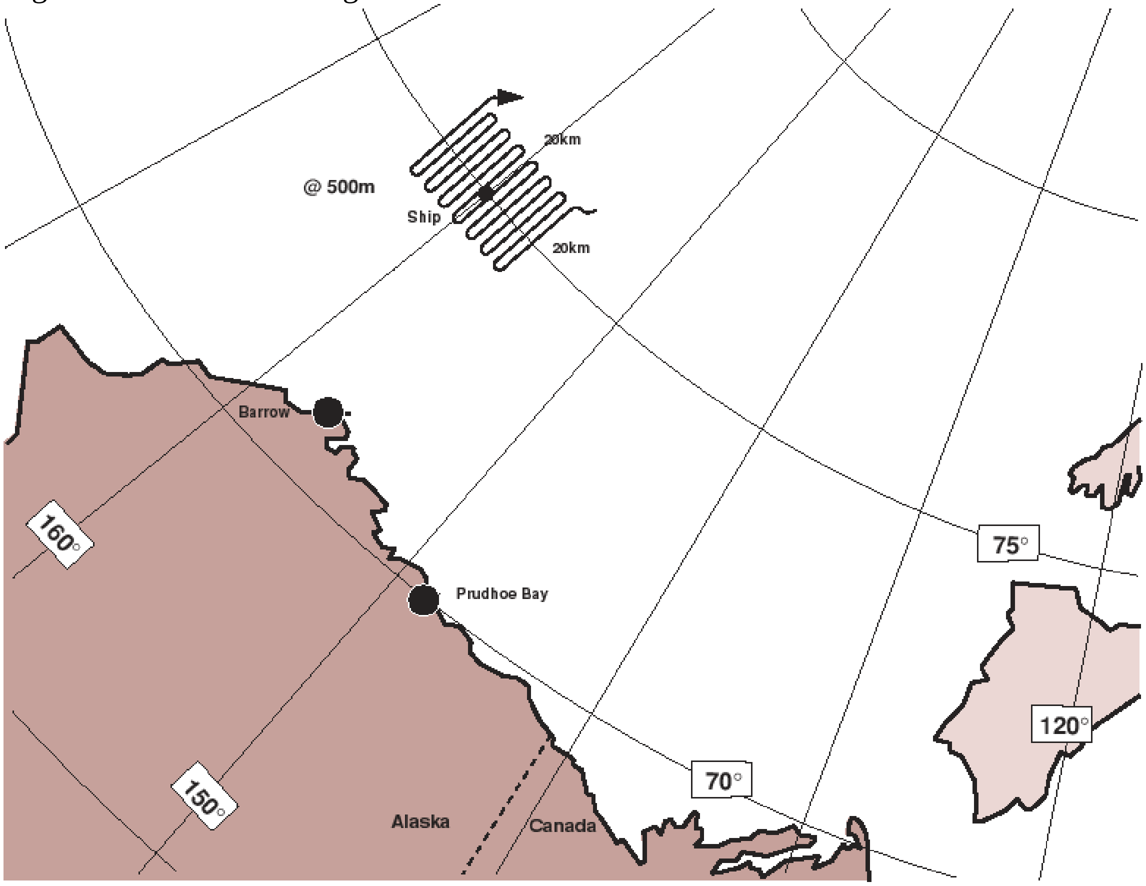


Figure 5.4.1-1c C-130 Flight Pattern-Ground Track

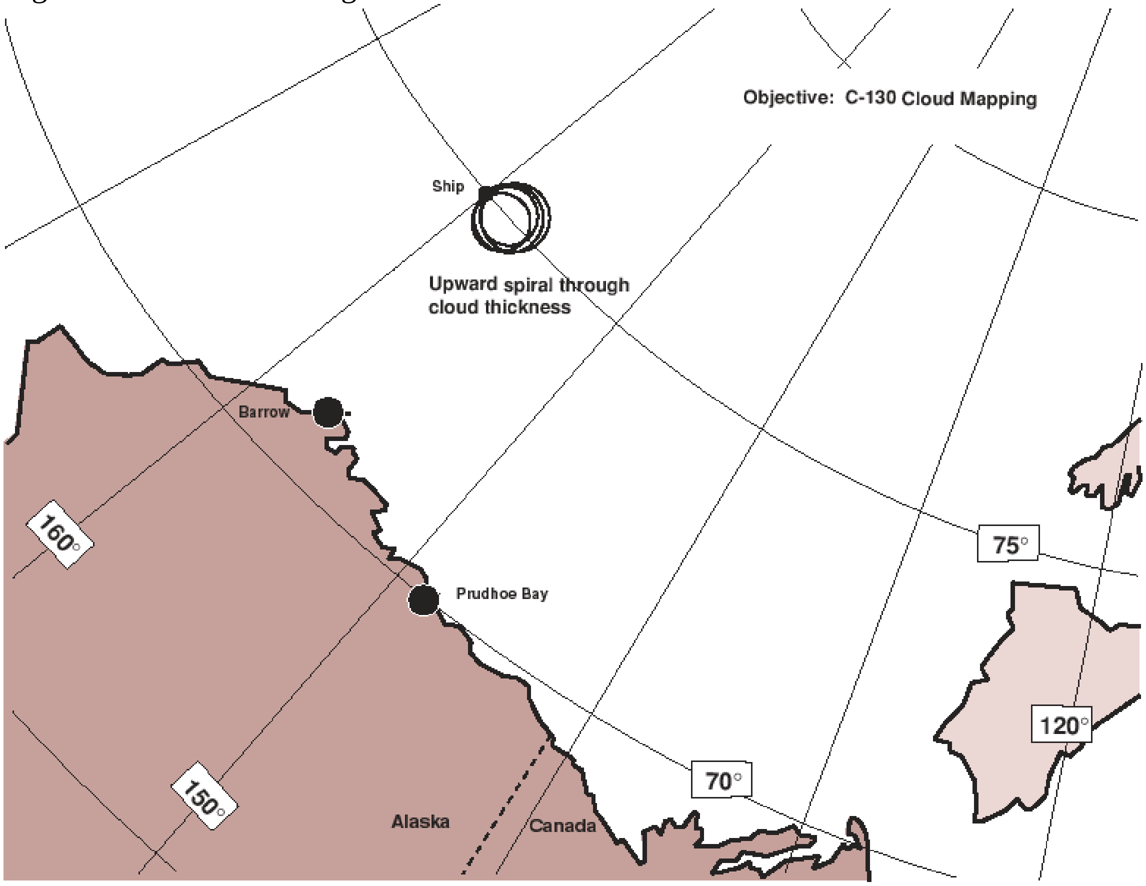


Figure 5.4.1-1d C-130 Flight Pattern-Ground Track

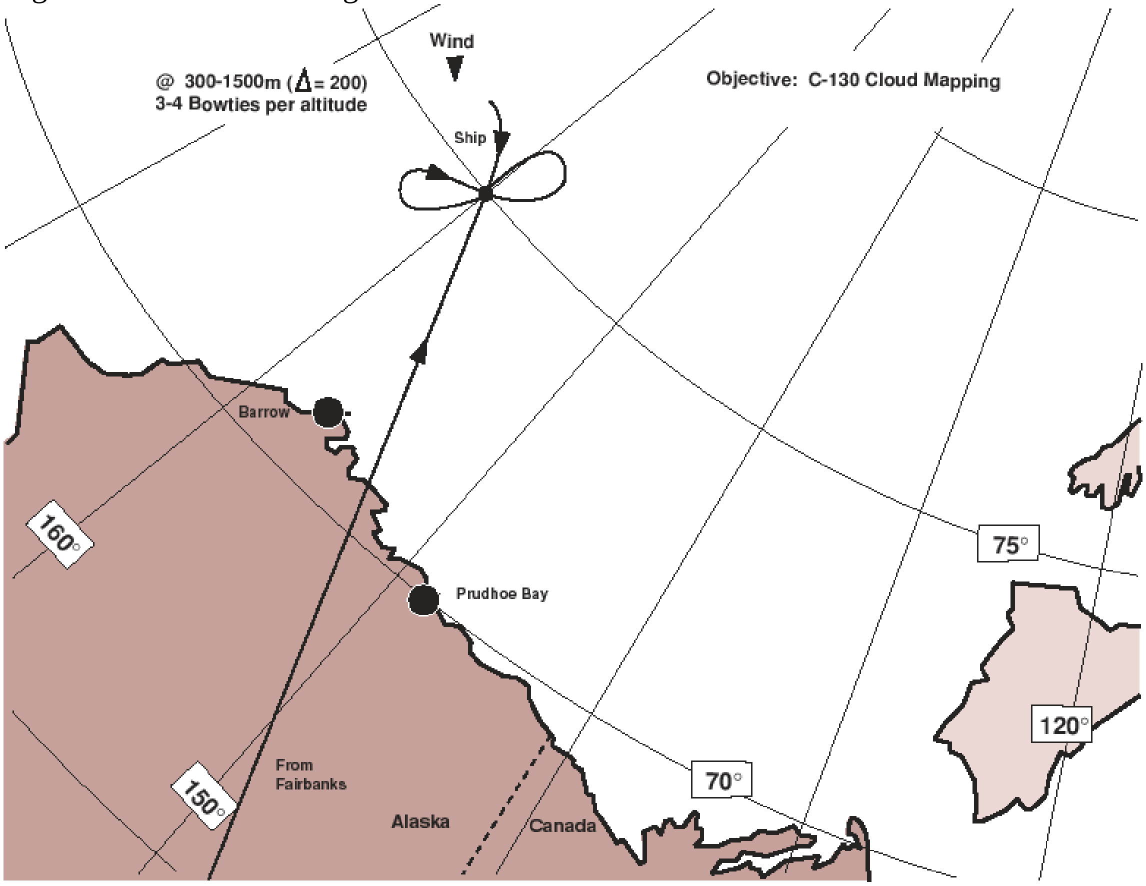


Figure 5.4.1-1e C-130 Flight Pattern-Elevation View

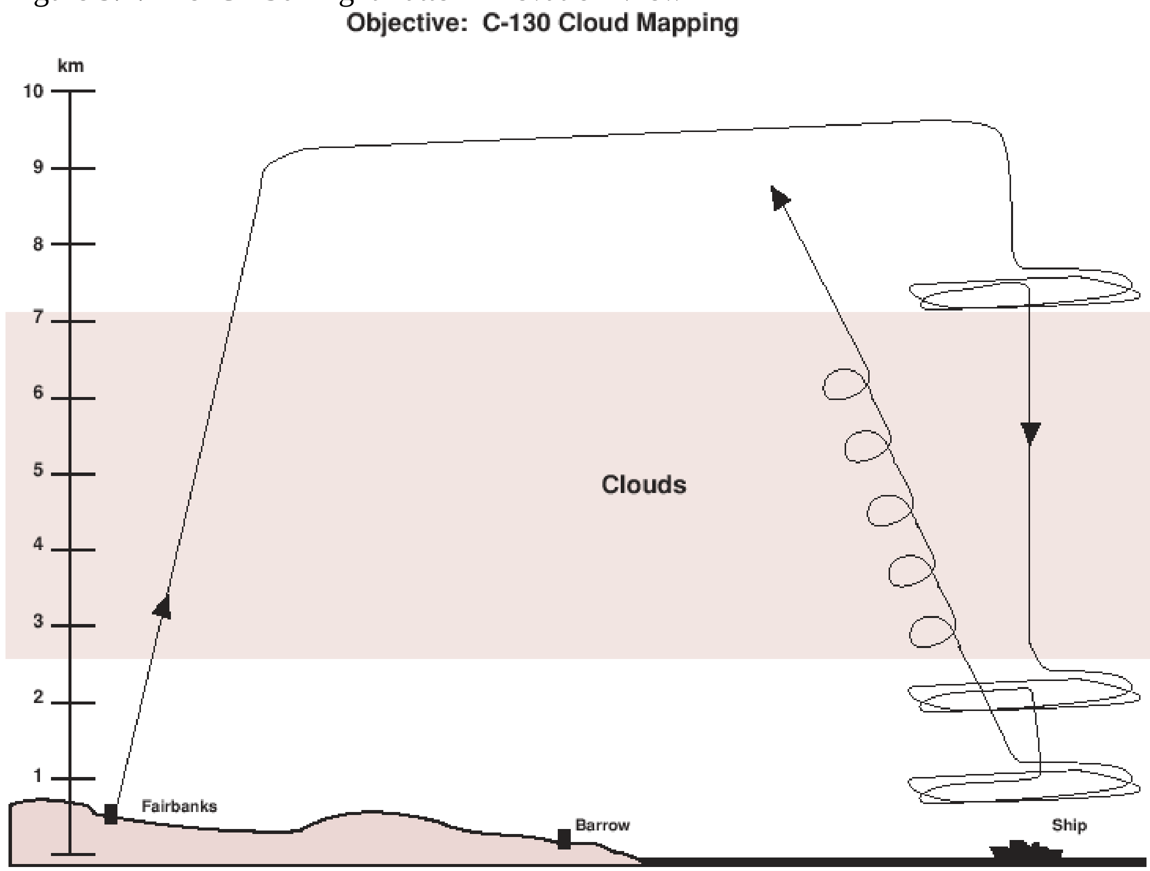


Figure 5.4.1-2a Canadian CV-580 Cloud Characterization and Budget Flight Pattern

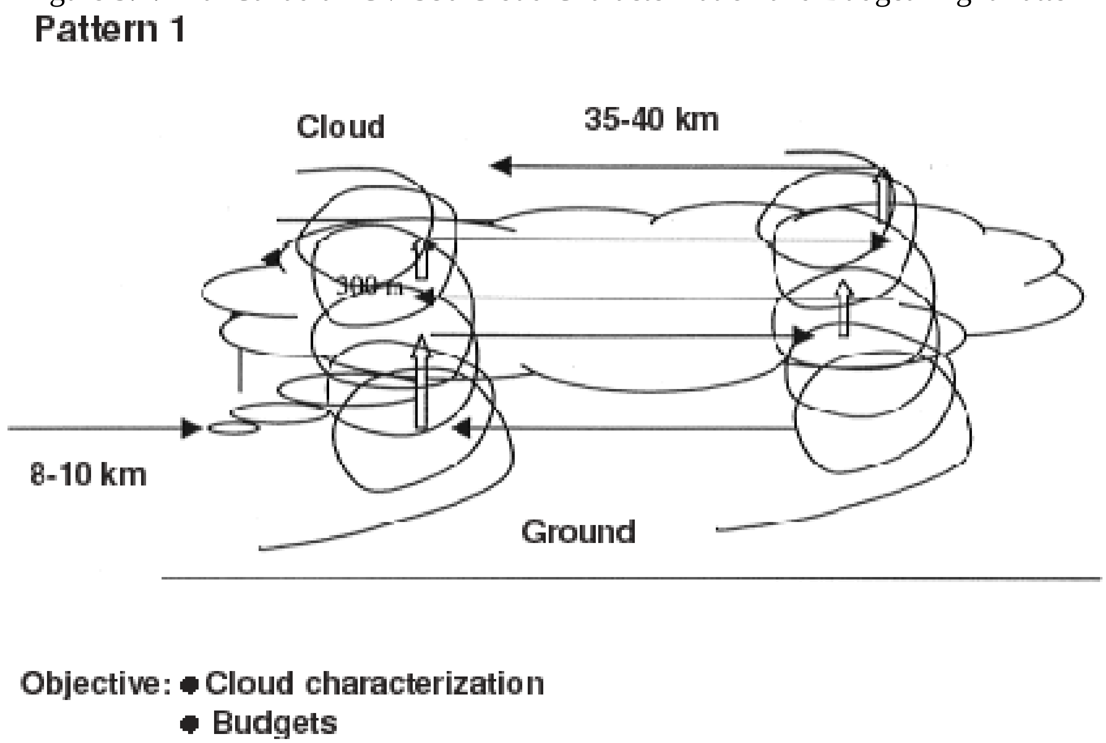
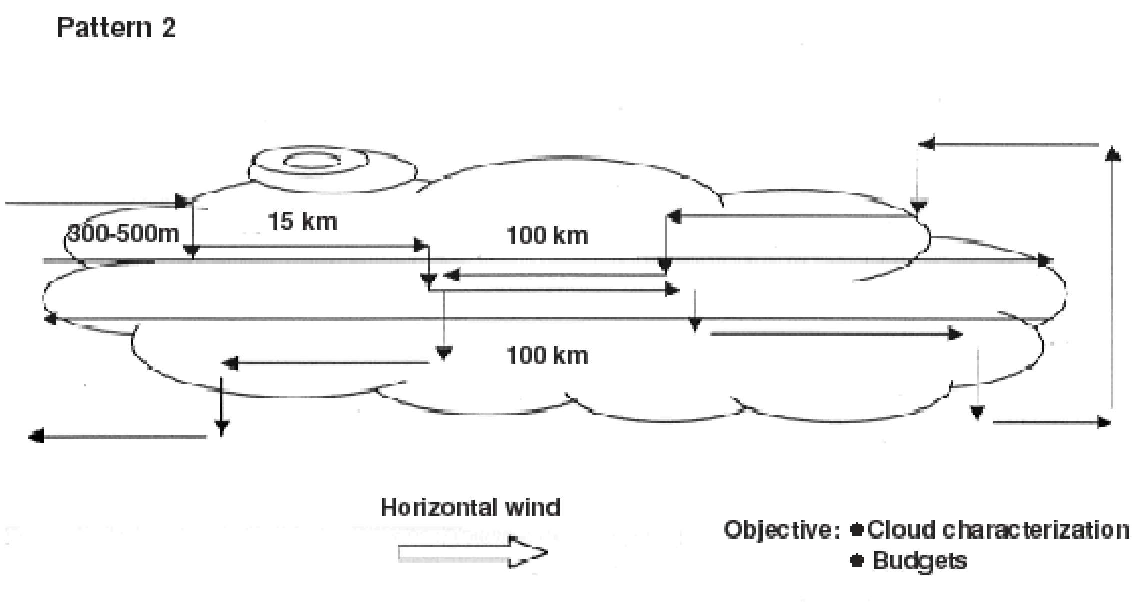


Figure 5.4.1-2b Canadian CV-580 Cloud Characterization and Budget Flight Pattern



5.4.2 Clear Stable Boundary Layer

These C-130 and Ultralight missions will be used to understand the dynamics of the clear stable boundary layer. They will also be used to map the surface characteristics in detail (in coordination with SHEBA). These data will also be used for remote sensing validation.

The flight pattern should remain over the same portion of ice as much as possible, so that approximately the same portion of the surface continues to be sampled. The flight pattern will consist generally of a series of boxes and L-patterns at a number of different levels in the atmosphere. At a single level, 100 km of measurements needed for turbulence statistics. Levels sampled by horizontal traverses should be at least 200 m apart. One side of box or L should be in the along-wind direction

1. Horizontal leg of about 50 km at the ferry level (for down-pointing scanners)
2. Descend to surface to assess vertical structure and depth of the B.L.
3. Ascend to 3 km, fly box pattern with 40 km on a side with intervening cross legs to map the surface.
4. Descend to 30-90 m, fly box pattern with 40 km on a side
5. Fly horizontal L-pattern 30 km on side at selected levels between 200 m and the B.L. top, with at least 200 m between levels
6. Ascend to above top of B.L.; descend to 30-90 m then ascent to above top of B.L. (profile)

TIME: 3 hours (depending on B.L. depth)

5.4.3 Clear Sky

This scenario is similar to that described in Section 5.4.2 for a clear stable boundary layer flight. The purpose is to map the characteristics of the surface around the surface sites to allow for a verification of satellite discrimination of clear and cloudy conditions. The flight pattern is a simple box pattern with crossing legs at one altitude designed to allow downward pointing instruments to map an area at least 50 to 100 km across at a spatial resolution that is at least sub-kilometer. The aircraft flight needs to be coordinated with the surface to insure that surface radiative fluxes and other surface instruments are operating during the flight. The aircraft of interest for this flight campaign are mainly the ER-2 and the C-130, but any aircraft operating instruments that make measurements at wavelengths (solar, thermal infrared and microwave) similar to those used by satellites will be of interest. The best strategy is to make simultaneous observations at as many wavelengths as possible. These observations should be augmented by lidar to characterize the amount of aerosol, if possible profiles of atmospheric temperature, humidity and ozone abundance are also needed.

5.4.4 Leads

The focus of these missions are relatively wide leads during spring, emphasizing leads of width 500 m or greater, preferably associated with steam fog or ice crystal plume. Both the Canadian Convair and C-130 will conduct these missions. Smaller leads will be examined by the Ultralight.

1. Confirm that lead is open with KT-19 (and AIMR)
2. On upwind side of the lead (at least 5 km from lead), obtain vertical profile
3. Obtain vertical profile downwind of lead (down, up, down, up), extending at least to 50 km downwind of lead
4. Fly a series of horizontal transects across the lead, extending from upwind edge of lead to 30X downwind of lead (where X is the lead width), not to exceed 60 km (use #3 as guide)
5. Fly horizontal transects over the lead, in the along-lead direction 20 km length if possible, at 3-4 different levels)

Figure 5.4.4-1a   Canadian Convair 580 Flight Pattern-Ground Track

Ship

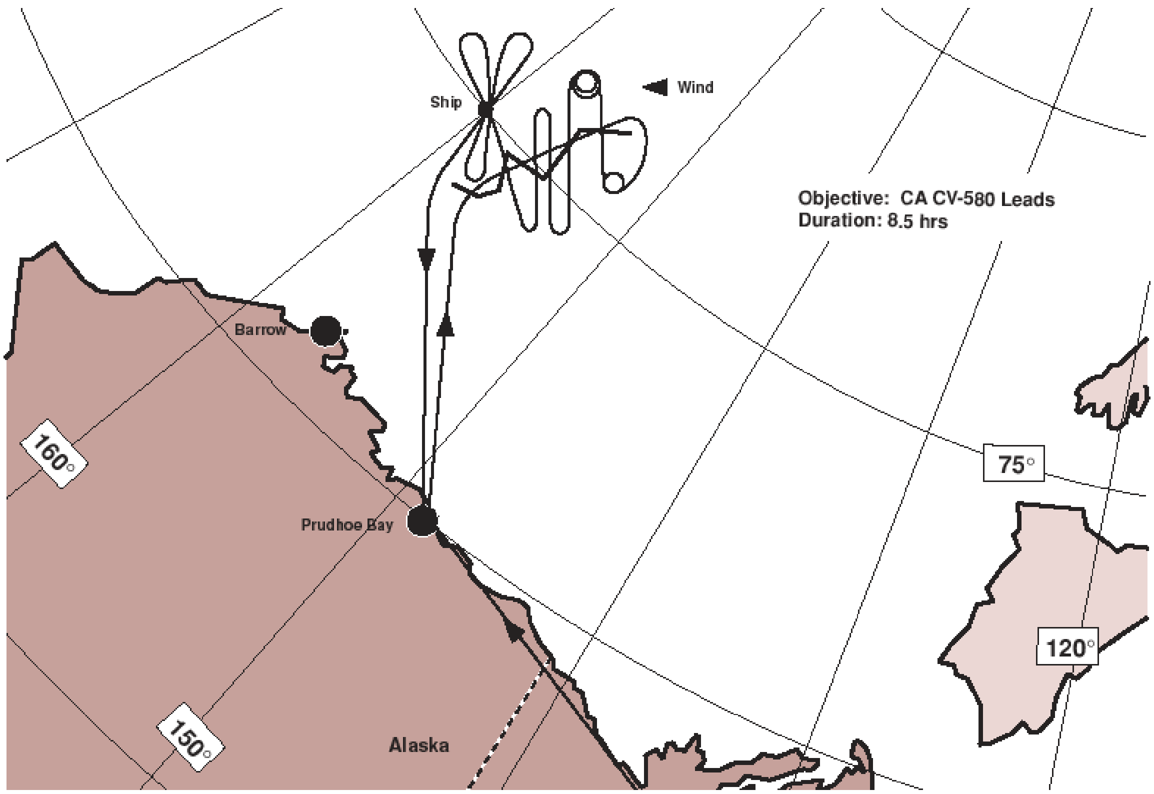


Figure 5.4.4-1b Canadian Convair 580 Flight Pattern-Elevation View

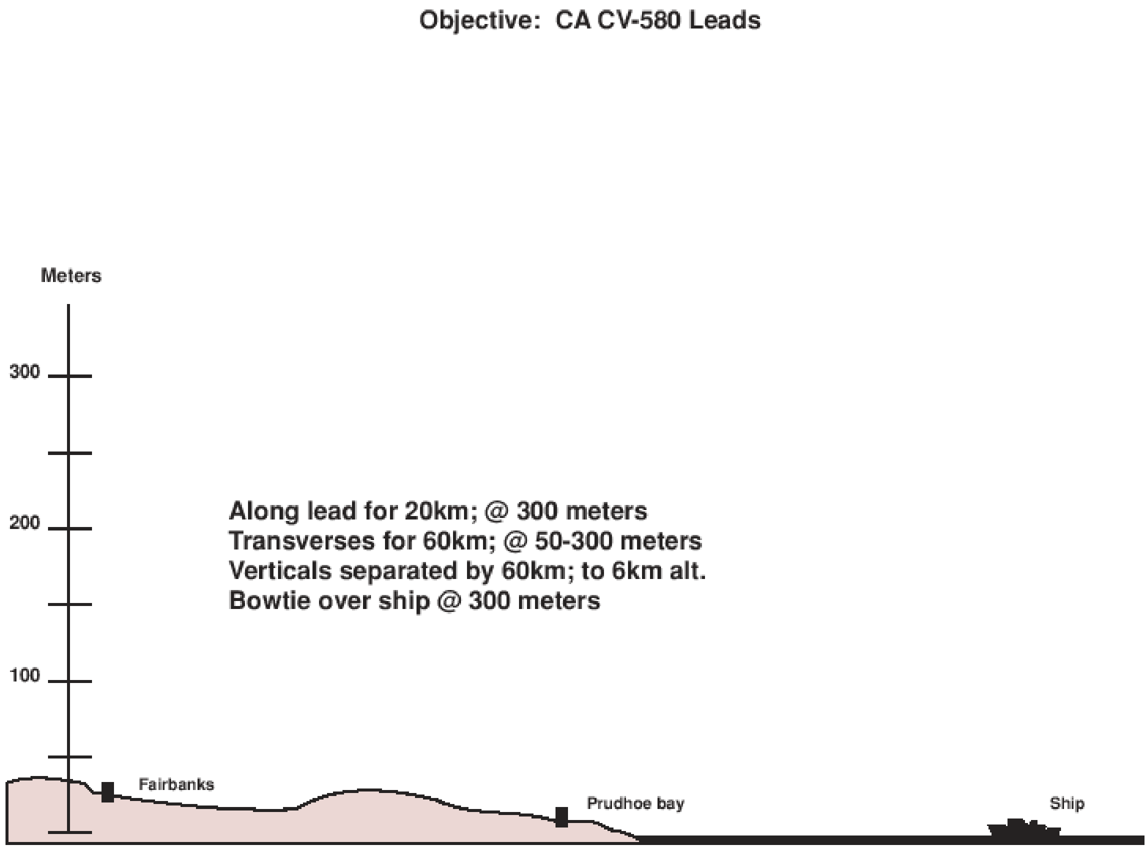
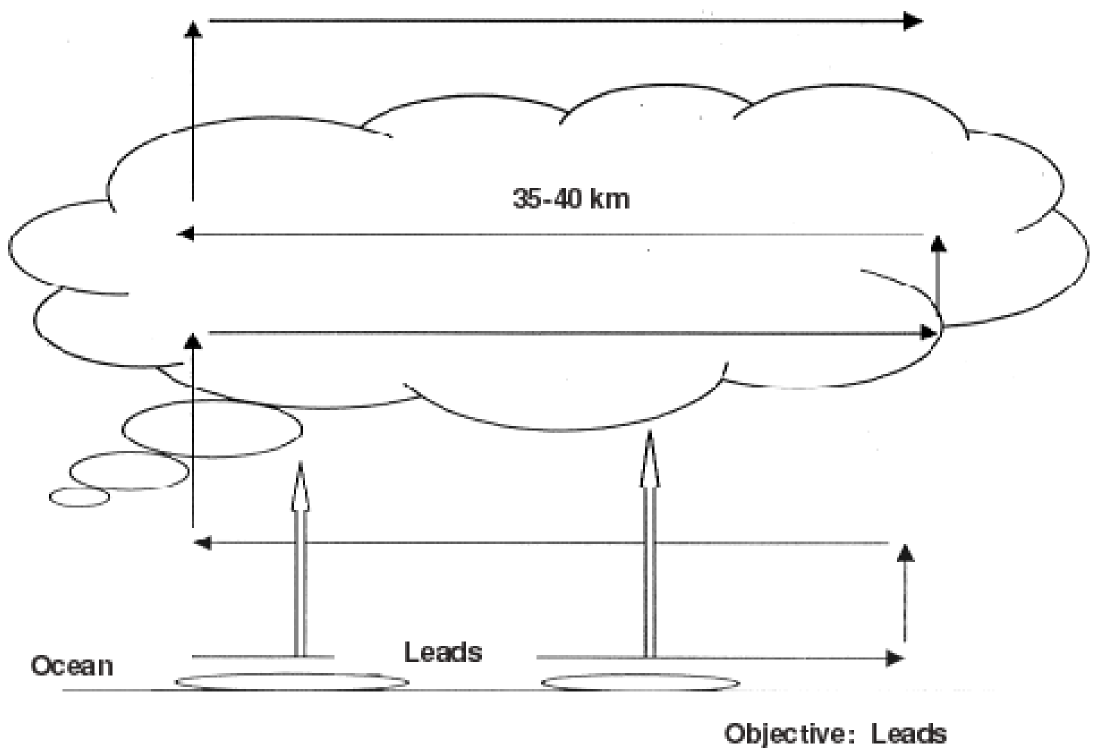


Figure 5.4.4-2   Canadian CV-580 Leads Flight Pattern

Pattern 3



5.4.5 Surface Sensor Validation

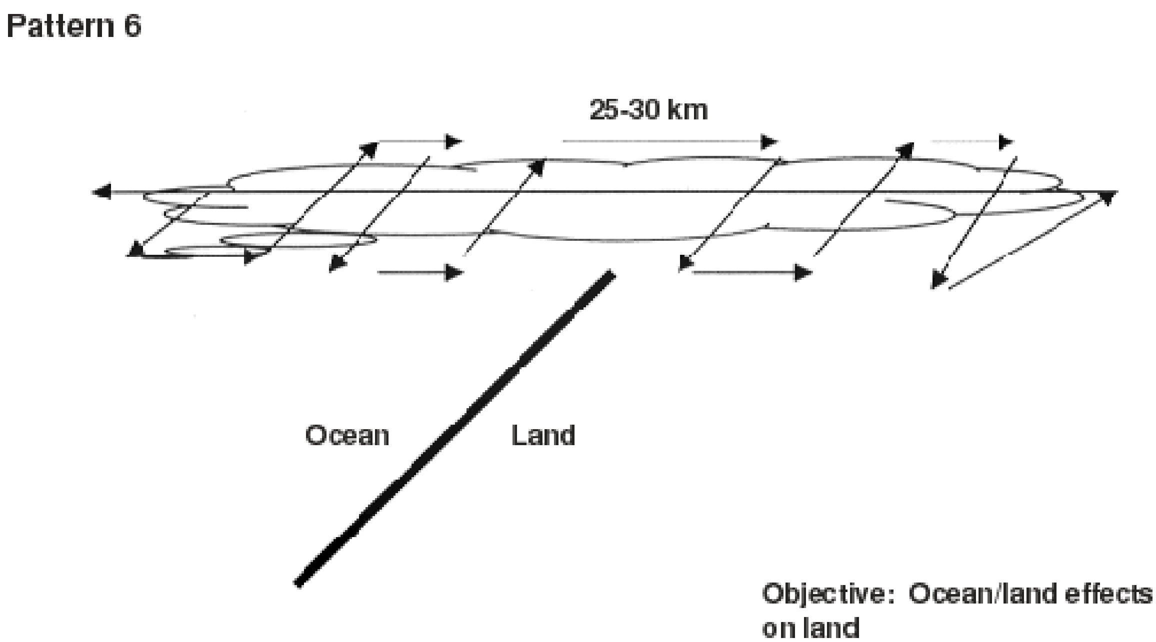
Missions should be selected on the basis of persistent cloudiness over the SHEBA site. The emphasis will be obtaining as many samples as possible over the surface site throughtout the depth of the cloud(s). In the event that there are multiple cloud layers, vertical profiles will be through all layers. Cloud penetrations should ideally be between 250 m to 1 km downwind of the profiling instruments and made cross wind to minimize modifying effects of aircraft exhaust on the the cloud microphysics measured by the surface sensors. Information on cloud boundaries will be provided via realtime communications from the cloud radar on board the ship and short flight legs will be flown at 4 different altitudes in each cloud layer, with the highest just below cloud top and the lowest just above cloud base. At the beginning and end of each flight track, aircraft will fly a descending or ascending spiral around the surface site with a turning radius adjusted so that aircraft mounted probes are not adversely affected by the banking angle. In general, because of the highly variable characteristics of cloud microphysics over short time and length scales, the aircraft measurements will not be useful for validation of surface-based retrievals unless they are within about 3 km of the surface site.

Additionally other priority missions (e.g. cloudy boundary layer, arctic haze etc) should maximize time over the surface site when possible without intefering with specific mission objectives.

5.4.6 Surface Mapping

The goal is to map the surface features over an area of 60 km^2 so that they are resolved on a spatial scale of tens of meters(larger area for ER-2). At a flight altitude of 5 km and a nominal air speed of 120 m s^{-1}, a complete survey of the surface will require four 60 km transects across the region, requiring approximately 1 hour of flight time.   A smaller region (20 $km)^2$ will also be mapped at a flight altitude of 1 km, to get a higher resolution mapping when surface features are complex (e.g. summertime melt ponds). For surface mapping, the primary concern is that the flight track be below the lowest cloud deck; clear-sky days are very favorable for surface surveys. Timing of satellite overpasses will be a substantial consideration in flight planning (both AVHRR and SAR).

Figure 5.4.6-1 Canadian CV-580 Flight Pattern for Land Effects



5.4.7 Cloud/radiation

This flight plan would be used for cirrus clouds and mid-level (e.g. altostratus, nimbostratus) clouds. Also may be used for mixed phase and ice phase boundary layer clouds, particularly if clouds and B.L. are horizontally inhomogeneous (on the mesoscale) and not suitable for cloudy boundary layer missions. Also, under icing conditions, only limited sampling may be possible within the cloud, making the cases unsuitable for cloudy boundary layer missions.

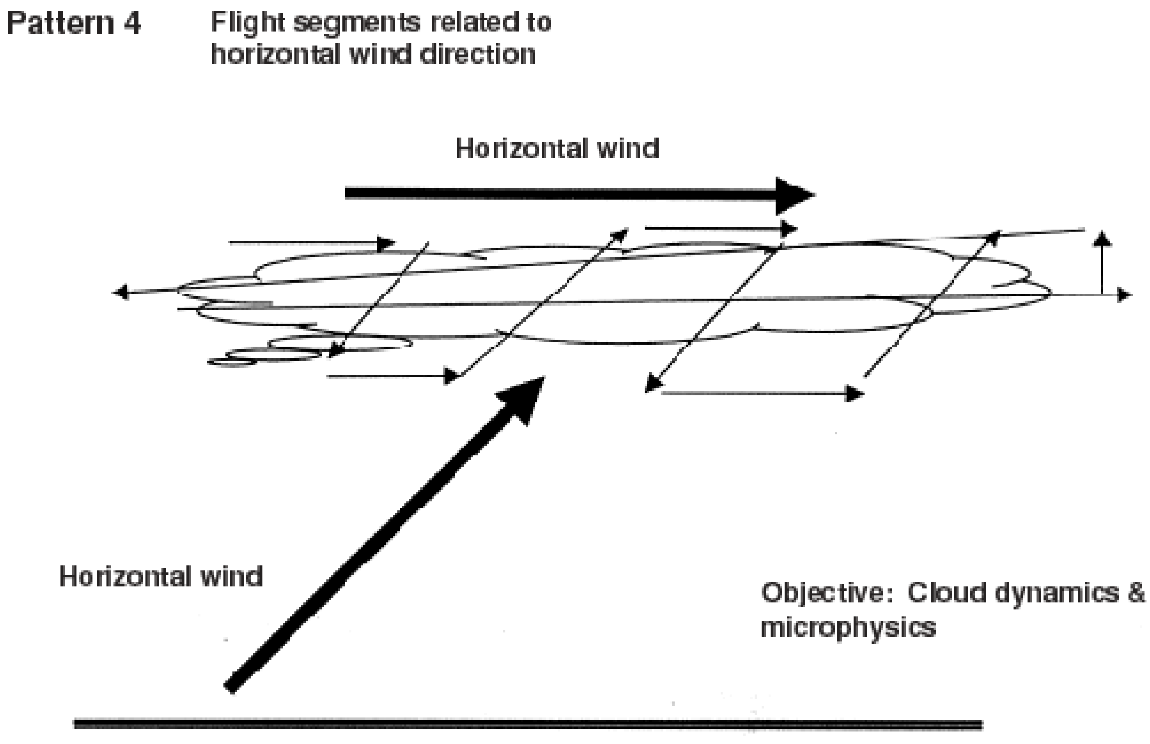
Select case based on perceived (mesoscale) horizontal homogeneity. Select both solid (e.g. cirrostratus) and broken (e.g. cirrocumulus) decks; make sure that there are no additional clouds overhead.

1. Horizontal leg at ferry level (significantly above cloud top) for C-130 (MCR).
2. Horizontal leg about 100 m above cloud top, at least 10 km long, another leg in reverse direction
3. Descend to below base
4. Horizontal leg about 100 m below cloud base, at least 10 km long, another leg in reverse direction
5. Ascend to within cloud. Fly at least 2 horizontal legs (about 10 km in length) at two different levels in the cloud, at least 200 m apart.
6. Ascend to above cloud top; descend to below cloud base (profiles).

** in potential icing situations, reduce length of in-cloud legs, in consultation with pilot

TIME: ~ 30 min.

Figure 5.4.7-1 Canadian CV-580 Cloud Dynamics and Microphysics Flight Pattern



5.4.8 Cloud Characterization

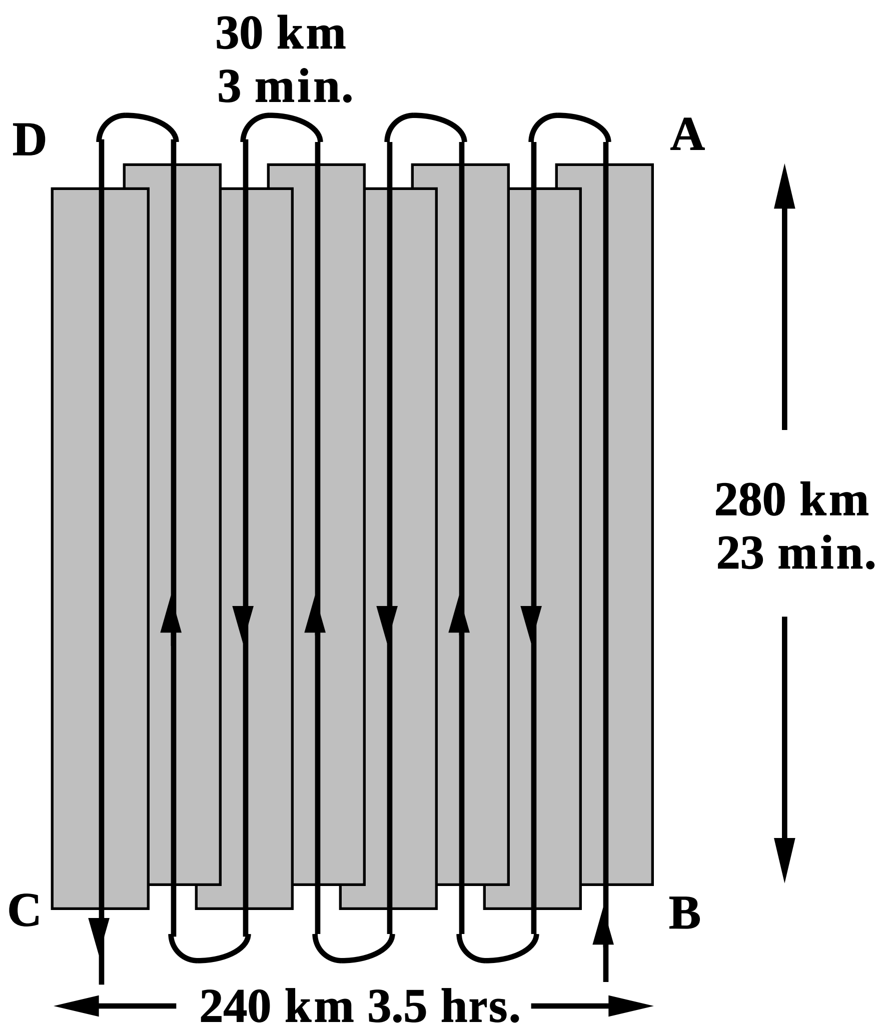
- **To obtain an unique data base for cloud masks in the arctic**

For many Earth remote sensing applications, cloud detection (or derivation of a cloud mask) is vital because the Earth is frequently covered by various types of clouds. The cloud mask indicates whether a given field of view has an unobstructed view of the Earth surface, or whether the pixel is cloud free but affected by cloud shadows. In the summertime Arctic, three distinct, relatively uniform surface types co-exist: green tundra, dark open ocean and bright snow and sea ice.

To achieve this goal, the ER-2 will fly a race track pattern, depicted in Figure 5.4.8-1, with flight legs about 30 km apart, commencing with (A-B) and concluding with (D-C). Turns between legs will require about 4 minutes. The ER-2 aircraft will primarily use MAS for measurements. Since the MAS swath width is 35 km, there is 5 km coverage overlap between adjacent legs. For a total of 8 legs, areal coverage is 280 km by 240 km and costs about 3.5 ER-2 hours on station. With proper rotation and translation, this flight pattern scenario will cover most of the area of interest. This cloud mapping flight for the ER-2 can be a stand-alone mission, but we prefer to coordinate with satellite overpasses and the U WA CV-580 making in situ measurements.

During the arctic summer, within the individual field of view of conventional satellites (e.g., a few km resolution), it is not uncommon to find rapid small-scale variations of open leads, melt ponds and refrozen leads, all of which have quite different reflectance characteristics. The high spatial resolution of these imagers will help to assess ways of convolving these small scale variations.

Figure 5.4.8-1 ER-2 flight pattern for cloud mapping.



- **To retrieve cloud properties over highly reflecting surfaces:**

It is well recognized that a knowledge of cloud properties and their variation in space and time is crucial to studies of regional and global climate change. Among all cloud properties, the cloud optical thickness (t_c) and effective particle radius (r_e) are especially important and can be studied through present remote sensing techniques and modeling efforts. We have applied our retrieval algorithm largely to reflectance measurements over the ocean where the underlying reflectance is low across the solar spectrum. Having low surface reflectance simplifies the problem of distinguishing t_c and r_e due to reducing the effect of multiple reflections between the cloud base and underlying surface. The data acquired for cloud mask development can also be used to investigate the effect of highly reflecting surfaces on

Figure 5.4.8-2   Stacked multi-aircraft flight pattern.

cloud retrieval algorithms. However, for the validation purposes, the ER-2 and C-131A will coordinate for vertically stacked multi-aircraft missions, depicted in Figure 5.4.8-2, above.

The ER-2 will fly 4 horizontal legs (A-B, B-A, A-B, B-A), each 280 km in length. The U WA CV-580 will fly collocated legs 110 km in length, due to slower speed (about 40% that of the ER-2). The U WA CV-580 will fly inside the cloud at about 1/3 of cloud thickness below the cloud top to measure cloud microphysics. Another two horizontal legs (C-D, D-C) are needed if the imagers are not scanning in the principal plane during the previous legs (A-B). Under the proper solar geometry and cloudy conditions, the imagers can measure the glory pattern in the anti-solar direction, providing an independent way to retrieve cloud physical properties. During these legs (C-D), the U WA Cv-580 is also required to measure cloud microphysics for retrieval validation. A 280 km leg will consume about 23 minutes of ER-2 time, and about 7 minutes to make a turn. Therefore, it will take about 30 minutes to complete one leg (A-B), and about 3 hours on station. The radiosondes from Barrow and ancillary weather data will help correcting the atmospheric effects in retrieval algorithms. This objective will be maximized when good coordination with satellite overpasses is met.

- **To study droplet absorption in the diffusion domain:**

The cloud absorption anomaly is an age-old problem in the cloud-radiation community. More recent measurements from TOGA-COARE and CEPEX have continued to fuel this controversy. Theoretical studies show that the absorption by cloud particles increases essentially with increasing values of r_e but the rate of increase depends on the absorption strength of water at individual wavelengths. This relationship has not yet been validated extensively through experimental observations. By applying the diffusion domain method the droplet absorption can be derived from the ratio of the measured nadir-to-zenith intensities (a relative quantity and independent of absolute calibration of the instrument) deep within a cloud layer.
Measurements from the CAR onboard the U WA CV-580 aircraft, together with microphysical data, will allow us to study statistically the relationship between cloud optical properties (e.g., single-scattering albedo or similarity parameter) and microphysical parameters (e.g., effective particle radius, cross-section area, and total volume). The U WA CV-580 aircraft will fly level inside the cloud layer, searching for and staying in the diffusion domain regime. At the end of diffusion domain measurements, the U WA CV-580 aircraft will fly just below cloud to obtain surface spectral albedo. This is a single aircraft mission as indicated in figure 5.4.8-3 or can be combined with the ER-2 mapping mission.

Figure 5.4.8-3 Proposed U WA CV-580 Flight Pattern

Assumptions: (1) SHEBA site is ~250 nautical miles from Barrow or less
(2) Fuel reserve available for Prudhoe Bay

Time from T/O to 15000ft over Ship = 68 minutes
Time from leaving 8000 ft over Ship to landing = 66 minutes
Total research time over Ship = 3.8 hours

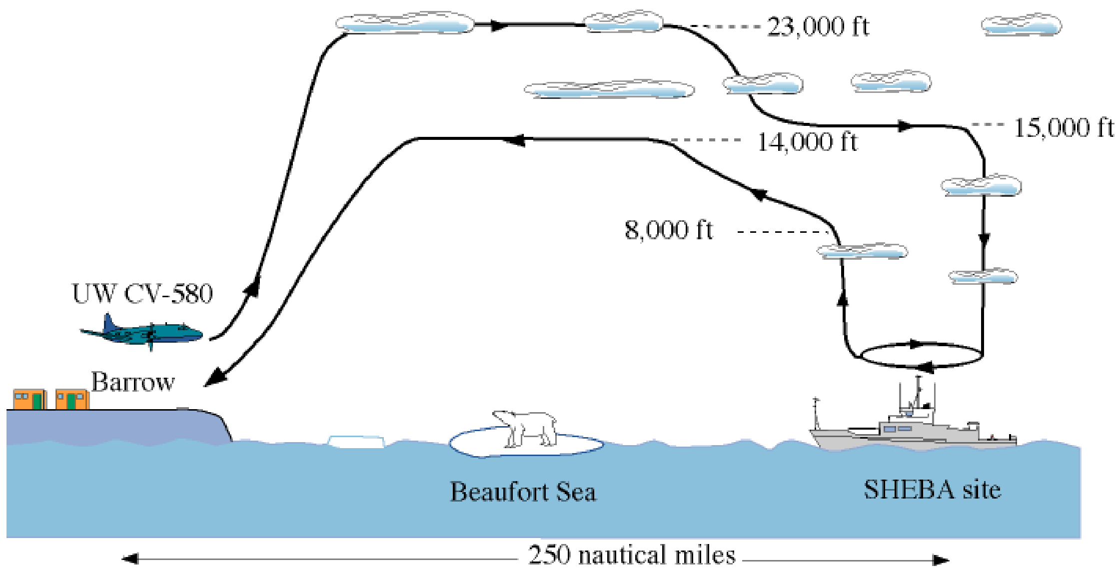
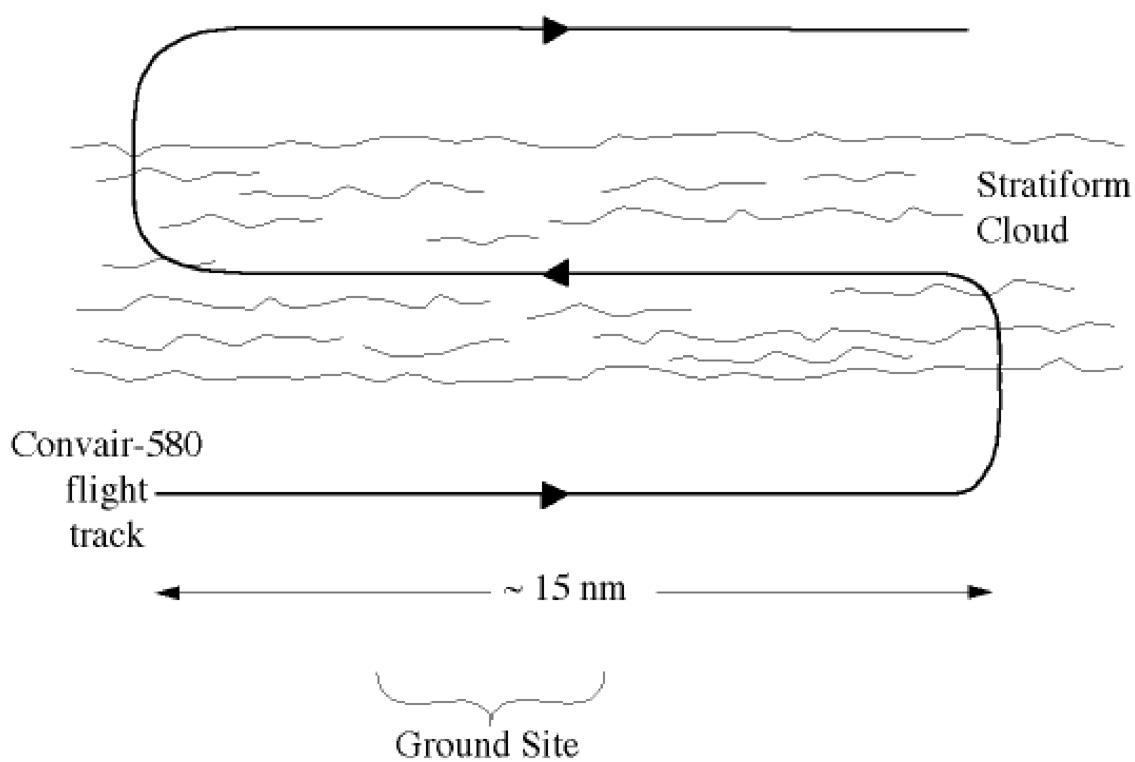


Figure 5.4.8-4 Schematic of a typical UW Convair-580 flight pattern in the presence of stratiform clouds



In the case of more than one cloud layer, other layers will be sampled if possible. The ground site is preferably the Barrow ARM site or the SHEBA ice station and, when possible the ER-2 is flying above. The flight path is slightly downwind of the ground site and the horizontal flight legs are oriented perpendicular to the ambient wind (to avoid aircraft effluents affecting remote sensing measurements from the ground). When the ER-2 is above, the Convair-580 flight legs should be directly under the ER-2 and closely aligned in space and time.

- **To study the statistical properties of cloud microphysics:**

Although Arctic stratus clouds often have a plane-parallel appearance, they can exhibit considerable spatial and temporal variability in their microphysical properties (e.g., liquid water content). It is expected that frequency spectra of these measurements follow a power law. Moments of various orders are calculated at different scales by averaging the data. The hierarchy of spectral exponents associated with these moments are useful statistics in characterizing cloud variability and breaks in the power spectra are associated with different physical processes occurring at that scale.
What is needed in this type of study are high resolution (e.g., 10 - 100 Hz) cloud microphysical measurements. The flight patterns of U WA CV-580 for this mission are straightforward. Following each profile measurements from below cloud base to above cloud top, the U WA CV-580 will fly three horizontal legs (e.g., 50-100 m below cloud top, middle of cloud layer, 50-100 m above cloud base) in which each leg contains at least 30 minutes of data. This is a single aircraft mission. It may be part of diffusion domain mission, or combined with the ER-2 mapping mission.

- **To measure bidirectional reflectance of various surface types:**

Accurate surface albedos are crucial input parameters to all climate models in assessing the effect of regional surface reflectance variations on the net Earth radiation budget and climate change. This is especially true in the Arctic for the marginal ice zone. Detailed measurements of the bidirectional reflectance properties of natural surfaces are also crucial to understanding and modeling their physical and radiative properties, as well as to aid in the remote sensing of aerosols and clouds above natural surfaces. To establish complete knowledge of the angular reflectance characteristics of the surface under investigation, it is best to synthesize airborne (or surface-based) scanning radiometer measurements.
The CAR measurements serve this purpose quite well, if a proper flight pattern is chosen, as illustrated in Figure 5.4.8-5. The U WA CV-580 will fly about 600 m above the surface in a circular orbit with aircraft banking (~20° roll) to the right. With the aircraft speed of ~80 m sec^{-1}, this will take about 2 minutes to complete an orbit and result in a ground track approximately 3 km in diameter. The pixel resolution at nadir is about 10 m and about 270 m at 80° viewing angle. Both measurements of the reflected and transmitted solar radiation will be used to reconstruct surface BRDF and sky radiance. However, sky radiance data within ~15° around zenith are lost due to the aircraft banking to the right. If the full sky radiance is needed, it can be obtained by banking the aircraft to the left. The targets for this mission are sea ice and snow, open ocean, arctic tundra, etc. under clear sky and various solar zenith angles. The bidirectional reflectance for sea ice and snow under complete cloud cover is also interesting. This is a single aircraft and stand-alone mission, but we will prefer to coordinate with satellite and ER-2 overpasses, as well as overfly the

Figure 5.4.8-5   Schematic illustration of circular flight pattern.

Ship and Barrow to compare with surface measurements as indicated in figures 5.4.8-6 and 5.4.8-7.

Figure 5.4.8-6 Elevation view for Intercomparison with Ground Measurements

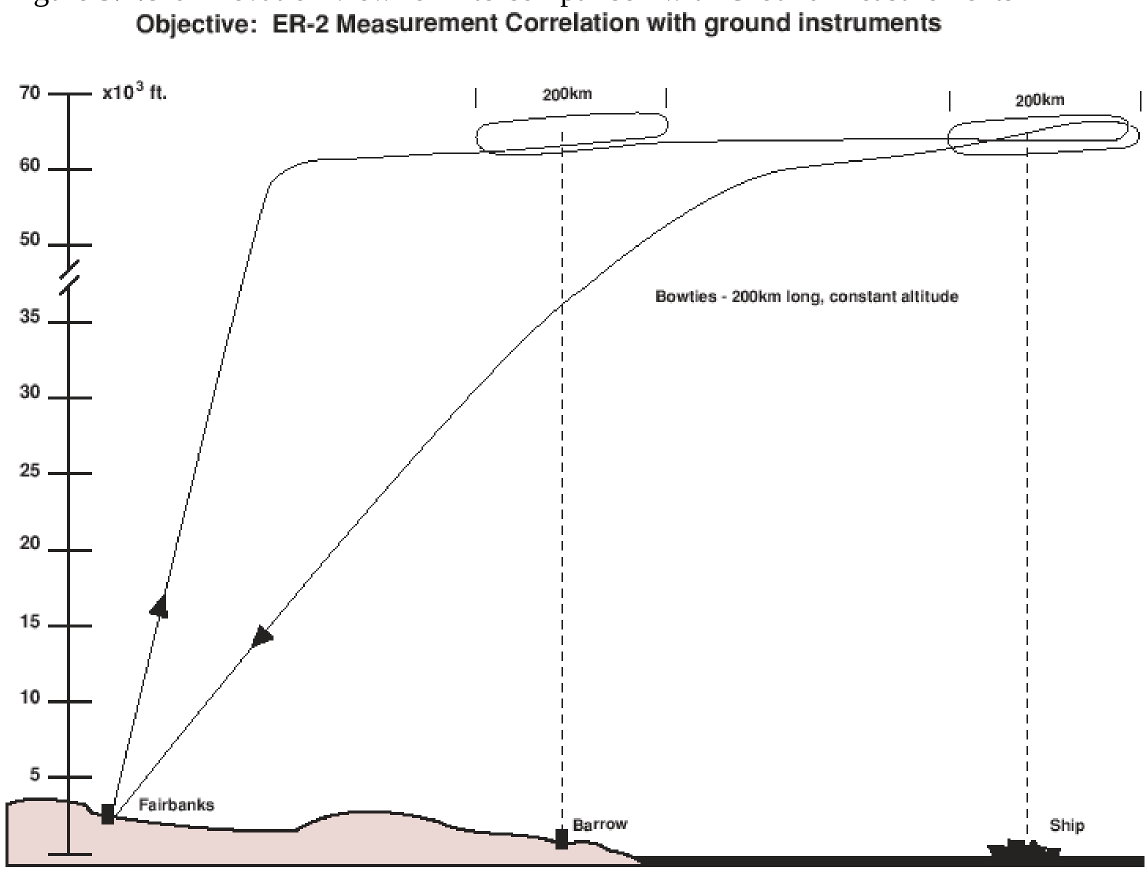
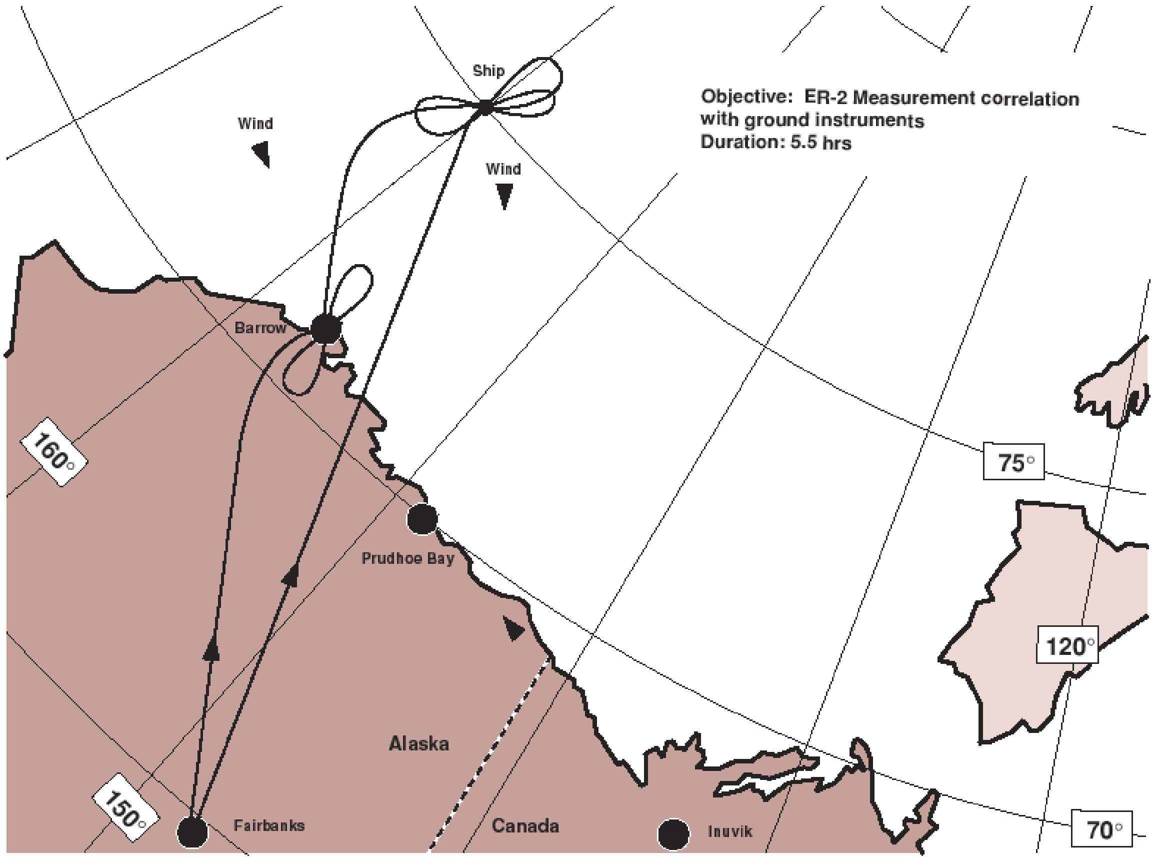


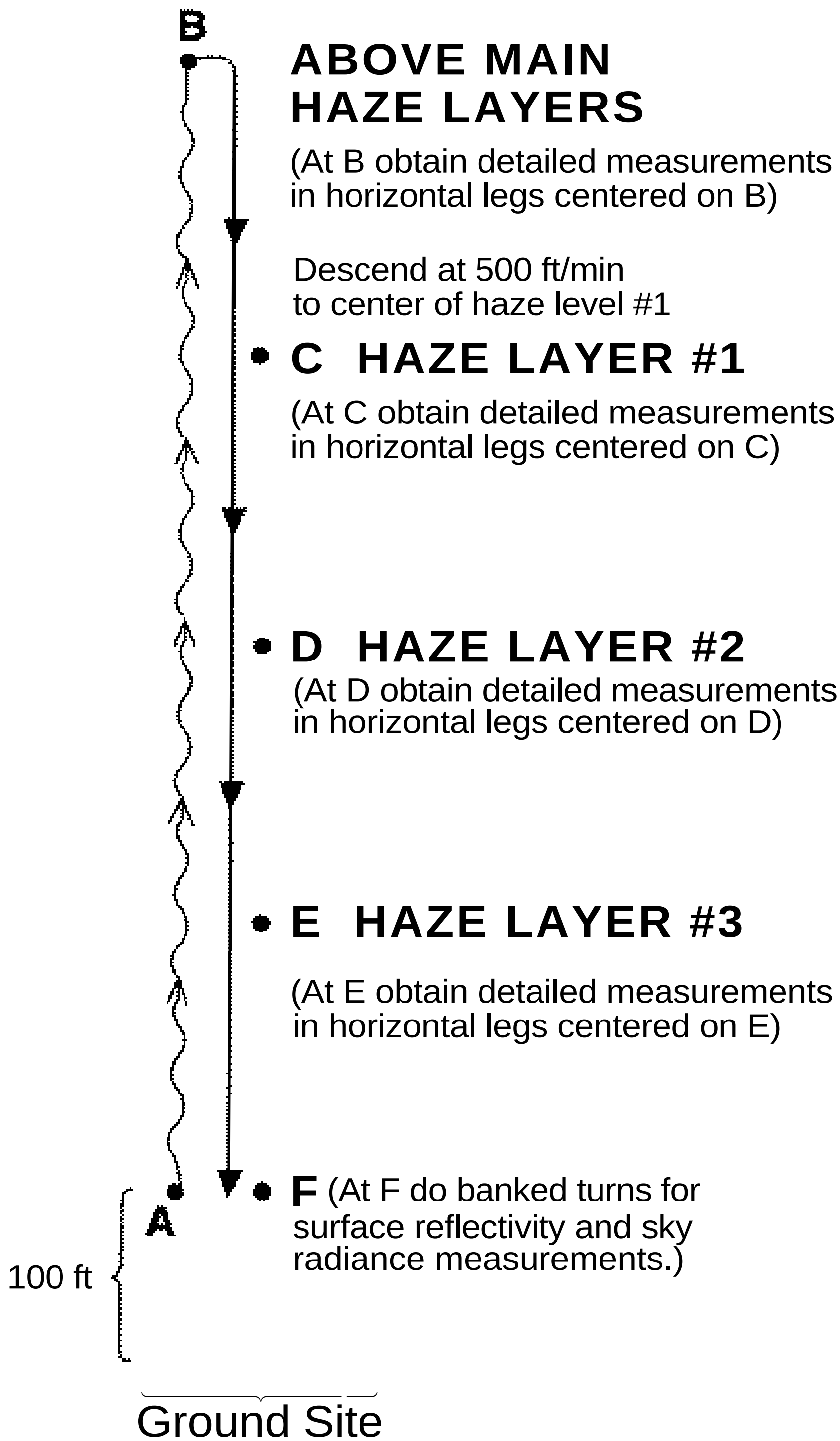
Figure 5.4.8-7 Ground Track for Intercomparison with Ground Measurements

Ship



5.4.9 Arctic Haze

Figure 5.4.9-1 Schematic of a typical UW Convair-580 flight pattern for aerosol measurements in absence of clouds.



The ground site is preferably the Barrow ARM site or the SHEBA ice station and, when possible the ER-2 is above. The flight path is slightly downwind of the ground site and the horizontal flight legs are oriented perpendicular to the ambient wind (to avoid aircraft effluents

5.4.10 ER-2 coordinated missions with UW and Canadian Convairs and NCAR C-130

A number of mission objectives focused on radiative processes can best be addressed through coordinated missions between the ER-2 and UW Convair or C-130, often in concert with satellite overpasses during some portion of the flight. These objectives include:

- Measurement of the cloud top altitude directly below the aircraft using downward looking lidar from above the clouds (ER-2 and Convair). These values can then be compared to comparable results derived from the CO_2 slicing channels (15 μm region) on the MODIS Airborne Simulator (MAS) aboard the ER-2.

- Validating and comparing the cloud optical thickness, effective droplet radius and liquid water content derived from remote sensing (ER-2) with comparable results obtained from nearly simultaneous in situ microphysical measurements (Convair, C-130).

- Measurement and analysis of the spectral absorption of solar radiation by clouds (Convair).

- Measurement of the bidirectional reflectance function of clouds (both layered and broken) for comparison with radiative transfer models and satellite observations (Convair).

- Measurement of the total broadband absorption of clouds through simultaneous measurements above and below clouds using intercalibrated Eppley pyranometers and solar spectral flux radiometers(SSFR) on UW CV-580.

- Comparison of the optical thickness of clouds derived from nearly simultaneous transmission (Convair, C-130) and reflection (ER-2 and satellite) measurements.

In order to meet these various objectives, a number of flight plans have been developed. One plan, for which the UW Convair is the only aircraft appropriately instrumented, consists of flying several clockwise circular orbits above clouds, each of which is some 5 minutes duration. The purpose here is to map the full bidirectional reflectance pattern ($0° < \theta < 90°$, $0° < \phi < 360°$) of clouds as a function of wavelength with the scanning Cloud Absorption Radiometer(CAR). Coordinated with these flights would be overflights with the ER-2, as well as NOAA POES satellites, plus nearly simultaneous in situ measurements from the C-130 (or subsequent in situ measurements by the Convair). These measurements would be particularly useful if the glory pattern was apparent on the clouds, as the width of the glory (backscattered pattern) depends on effective particle radius, which could be validated from the in situ measurements (see figure 5.4-10-1). This flight pattern will take at most 30 min. and can therefore be incorporated within a larger mission objective for a flight day.

Figure 5.4.10-1a   ER-2/C-130 Intercomparison-Ground Track

Ship

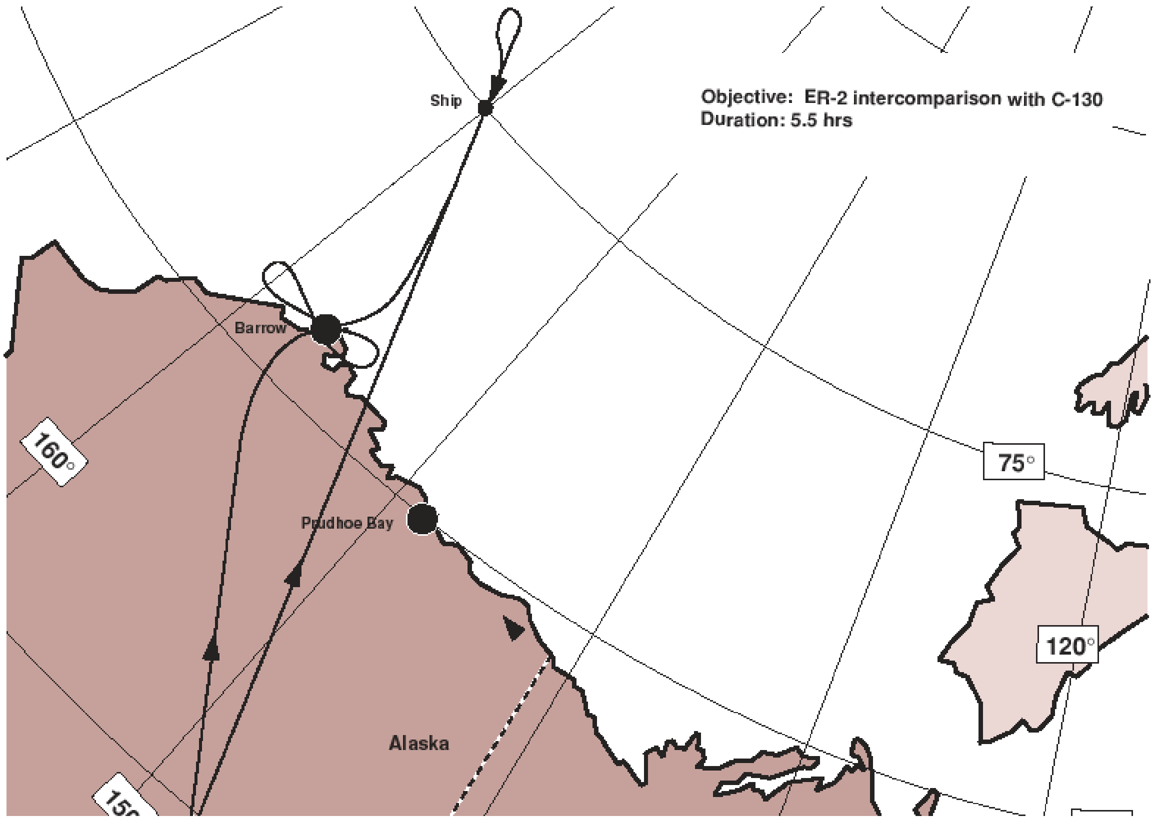
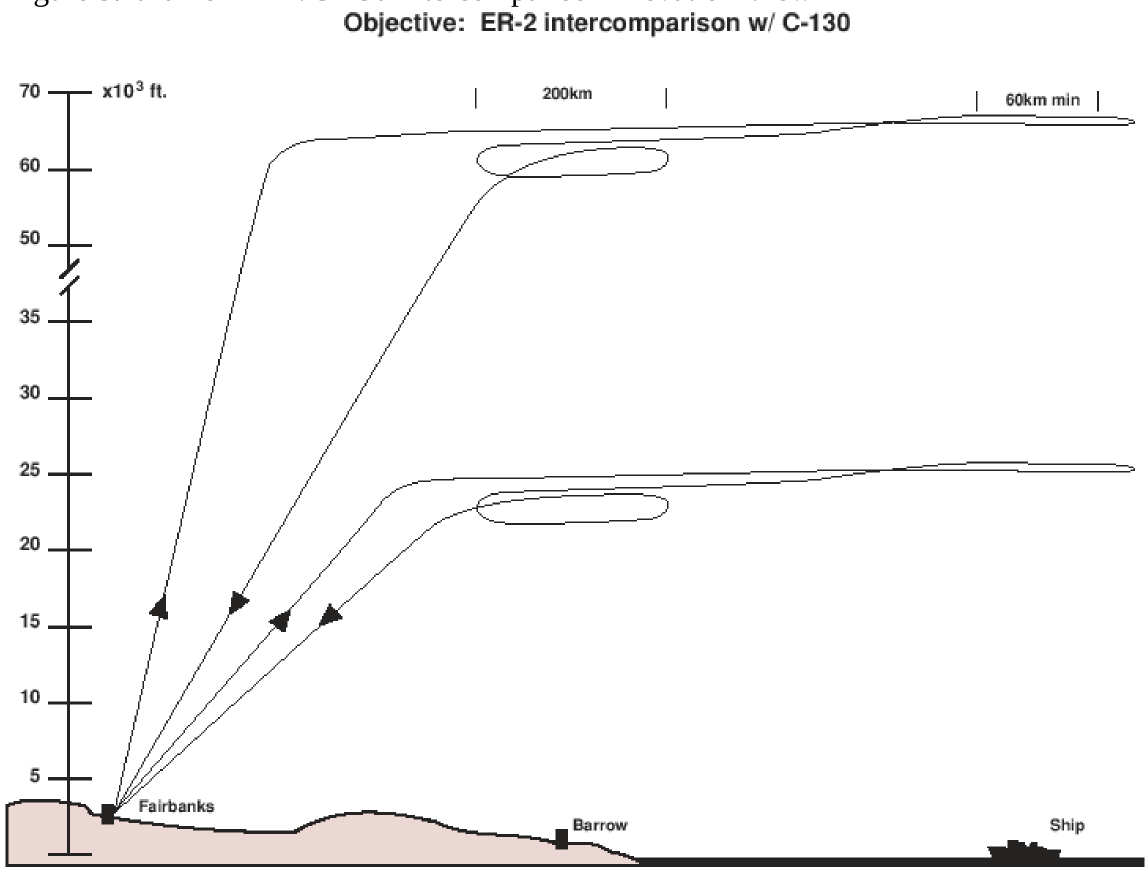


Figure 5.4.10-1b ER-2/C-130 Intercomparison-Elevation View



An additional flight pattern, shown in figure 5.4.10-2, is a straight forward stacking of the NASA ER-2 above and the UW Convair in the vicinity of the cloud, with horizontal legs above, within and below cloud. The above cloud MAS measurements from the ER-2 will be used to derive the cloud optical thickness and effective radius, as in FIRE-I, while the within cloud measurements will be used both for in situ validation of effective radius and for deriving the spectral absorption of the cloud layer using the diffusion domain method.

Figure 5.4.10-2a ER-2/U WA CV-580 Intercomparison-Ground Track

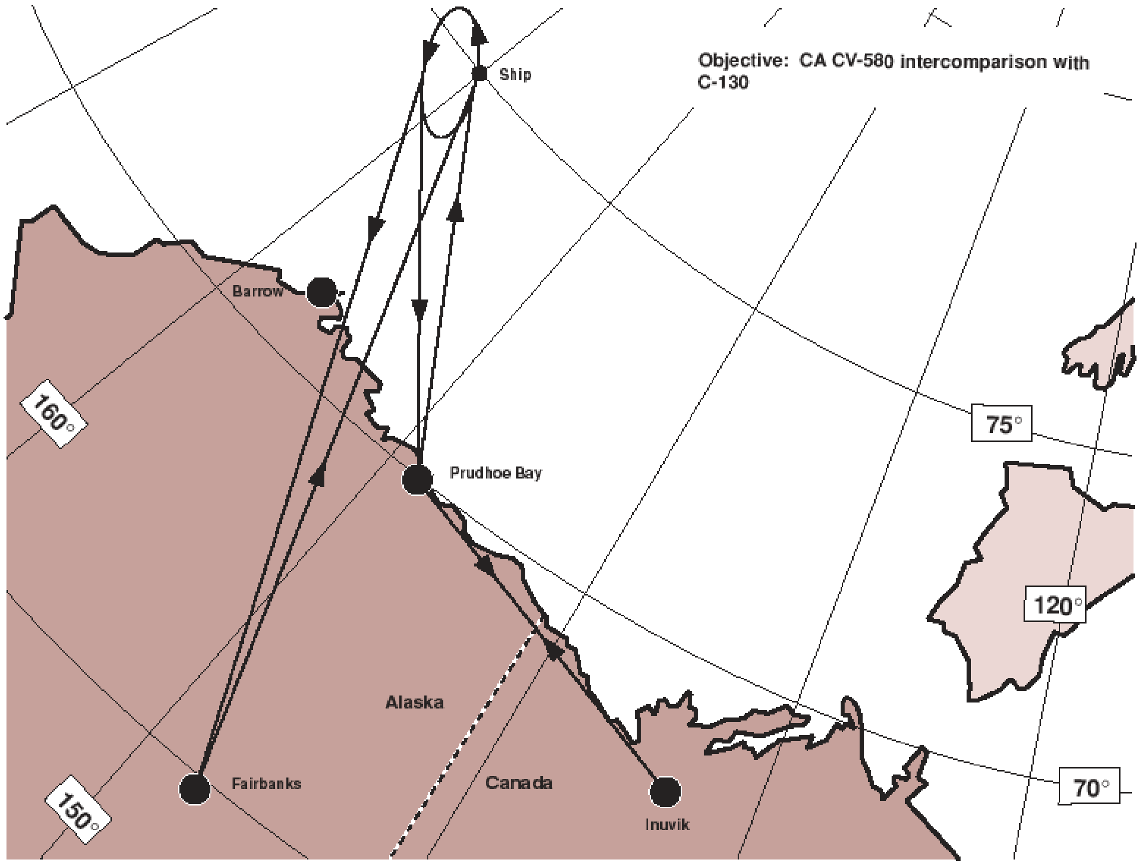
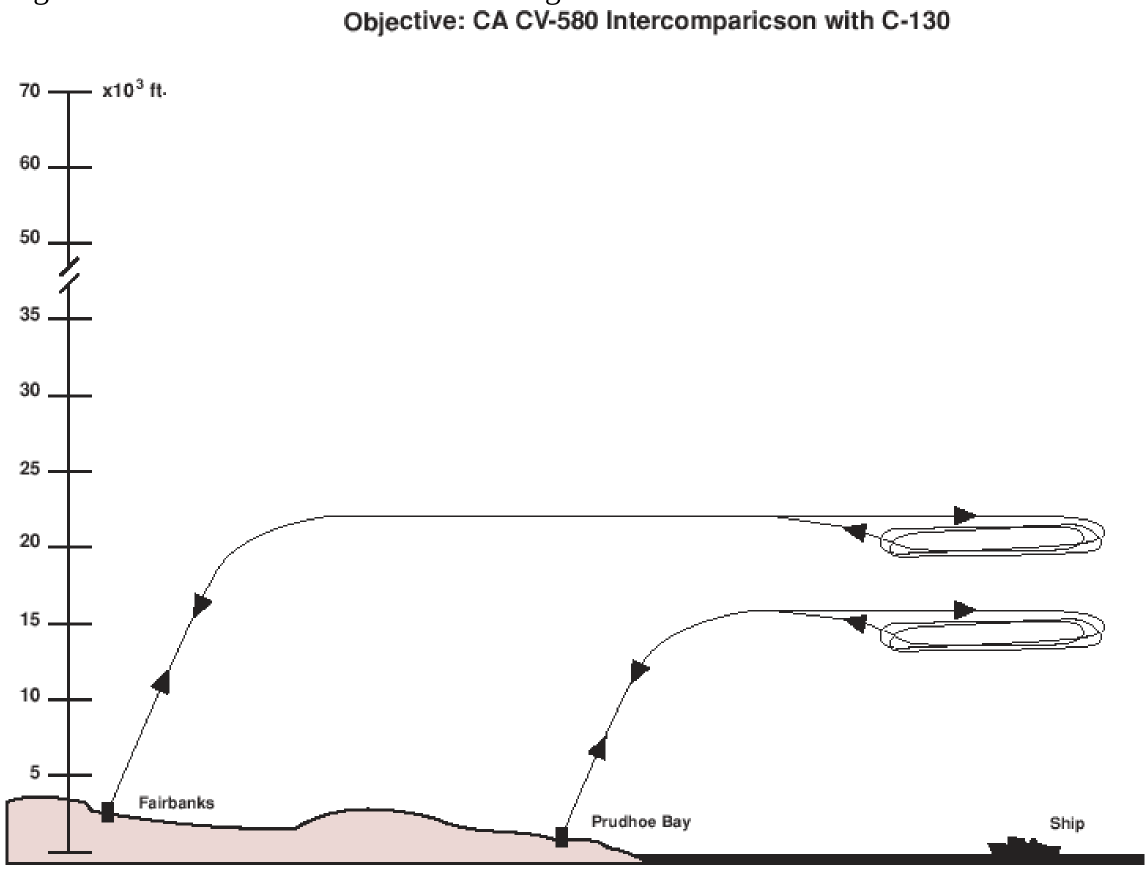


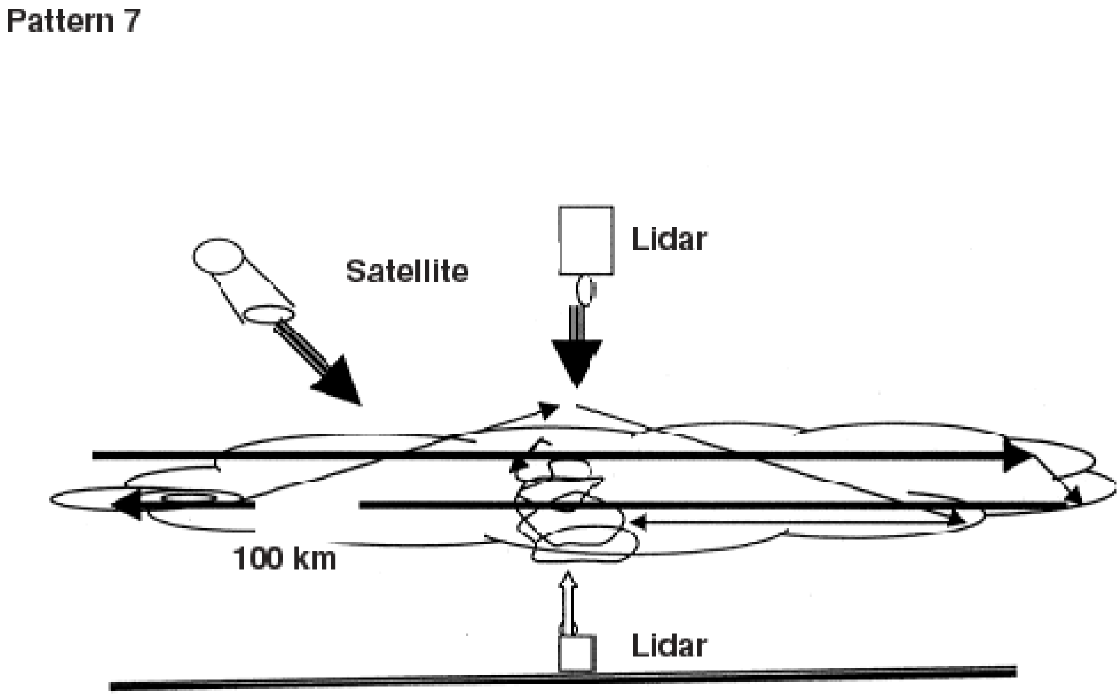
Figure 5.4.10-2b ER-2/U WA CV-580 Flight Pattern-Elevation View



5.4.11 Aircraft/Satellite Intercomparisons

Calibration of satellite, surface and aircraft radiometers is critical to the success of the FIRE III Arctic Cloud Experiment, especially for shortwave (i.e. solar) radiance measurements. The strategy for the inter-calibration of the satellite and aircraft imaging radiometers is similar to the FIRE II Cirrus experiment. Special missions will be flown to intercalibrate the ER-2, Convair, C-130 and satellite radiometers. In addition, missions should be conducted over the SHEBA and Barrow sites. The ER-2 MODIS Airborne Simulator (MAS) radiometer will be used as the transfer standard. Section D.2.2 of Appendix D shows the spectral bandpasses for all 50 bands of MAS, which have been selected to optimize intercalibration of current satellite radiometers (mainly AVHRR) and provide a preview of MODIS data on future EOS spacecraft. This requires coordinated ER-2 flights with the other aircraft and during satellite overpasses, so that the MAS has similar viewing geometry to the satellite radiometers. Predictions of satellite overpass and control of the ER-2 flight path (plus or minus 5 minutes) should allow matching of viewing angles to within 2-5 degrees. Intercalibration data should be collected over thick cloud layers and open ocean, if the opportunity arises, and within 15 degrees (preferred, 30 degrees acceptable) of nadir view. Cloud height information from the ER-2 lidar is desirable, as well as wind information, if available. The analysis procedure follows that described in Wielicki et al. (1990). Such intercalibration flights should be conducted once near the beginning and once near the end of the experimental period, requiring about 4.5 flight hours. The actual time devoted to the calibration measurements is less than 15 minutes per flight. Since the satellite ground tracks are nearly north-south oriented, the ER-2 flight track along this direction will usually be perpendicular to the wind direction as required for other experiment objectives. Intercalibration flights will be conducted at least once both for NOAA 12 and NOAA 14.

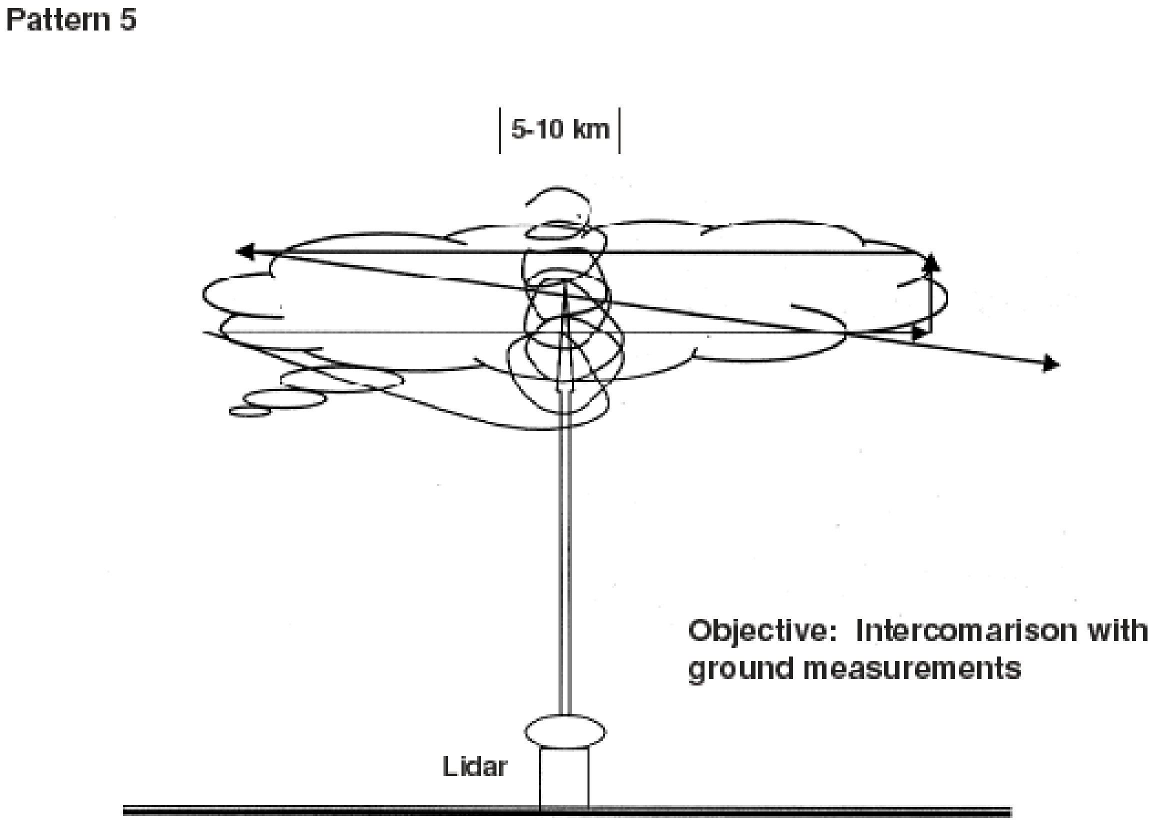
Figure 5.4.11-1 Canadian CV-580 Flight Pattern



5.4.12 Convair/Surface Intercomparisons

Aircraft measurements upwind and over the surface stations will provide important information on spatial structure and in situ data for comparison with remote sensing measurements. Aircraft will be used to measure cloud microphysical properties, liquid water content and vertical profiles of liquid density, turbulence structure, radiative fluxes, and chemical and aerosol properties for improved interpretation of data from the surface-based remote sensors.

Figure 5.4.12-1 Convair CV-580 Flight Pattern for Ground Instrument Intercomparison



5.4.13 SHEBA Aircraft

The Ultralight will fly for a total of 300 hours for SHEBA, for missions of 4-6 hours. Several flights per week are possible. The following general flight patterns will be flown:

- Mapping survey on scale of (20 km x 20 km) at a nominal flight altitude of 300-1000 m (below cloud base), consisting of about 20 transects of 20 km length. This survey must be done by flying below cloud base, and will provide surface characteristics from the video, surface temperature, directional and hemispheric surface albedo (about 4 hours flight time).
- Horizontal transects of 20 km length, from an altitude of 10m at the slowest possible flight speed, for high-resolution observations of the surface characteristics (radar) and turbulent and radiative fluxes.
- Lead and ridge IOPs consisting of transects across the feature at various altitudes and along the feature (including up and downwind transects).

At least one mapping survey will be conducted each week. Missions to conduct horizontal transects will be coordinated with Andreas/Fairall and Curry et al. and with measurement and other surveys near the camp (e.g. Perovich et al.). Missions to conduct lead and ridge IOPs will depend on the availability of suitable features and will be coordinated with the mobile flux stations of Andreas/Fairall.

There will be a helicopter available at the camp from June-October 1998 to conduct survey flights. Ideally, survey flights would be made every 3-4 days during the melt season and fall freeze-up. On each flight photographs will be taken to map the local area within 1-2 km of the ship, then a few 20 km legs centered on the camp will be flown to generate statistics regarding floes, melt ponds, leads and thin ice. Image analysis of these photographs will supply spatial, temporal and statistical information on the number, type, area, shape and connectivity of melt ponds, as well as data on floe size, floe perimeter, lead area and thin ice distribution. Statistics on ice concentration, pond fraction and pond type will be combined with local optical results and radiative transfer models to estimate how incoming shortwave radiation is divided between reflection and absorption by the ice, ponds and ocean mixed layer. Results from local lead studies will be used in conjunction with aerial data on ice concentration, lead temperatures, lead size and floe perimeter to obtain estimates of the amount of energy expended on lateral melting.

Survey flights will be made by the Twin Otter during the normally scheduled crew rotations, every six weeks. Conditions permitting, two flights will be made on the Twin Otter during each rotation period and on one of these flights additional fuel will be taken on at the ship in order to accomplish a more detailed survey of the ice around the ship. This survey will consist of a large butterfly pattern that would overfly the buoy installations. The size and shape of the pattern will be determined in consultation with the pilots. The preferred flight altitude is 1000 feet under optimal conditions. The main area of interest is near the camp, but if flying conditions and fuel supplies permit, surveys to and from the shore will also be accomplished.

5.5 Schedules and Operations Constraints

Table 5.5-1 presents the general period of operations for each aircraft, along with the total number of research flight hours for each aircraft.

Table 5.5-1 Aircraft Operation Period and Flight Hour Allocation

Airplane Designation	Operating Period	Flight Hours Available
NASA ER-2	5/15-6/7	50-Spring
NCAR C -130	5/4-28 Spring 7/6-7/30 Summer	90-Spring; 70-Summer
UW CV-580	5/15-6/13 Spring	80-Spring
Canadian CV-580	4/7-5/7 Spring	60-Spring
NOAA Ultralight	4/13-5/20 & TBD	300-Spring & Summer
Twin Otter	Spring & Summer	2 flts/3 wks Spring; 2 flts/6 wks Summer
Helicopter	Summer	2 flts/wk Summer

5.5.1 Summary of Crew Duty Limits

NCAR C-130:

Adequate rest for crew members is essential for safe operations of NCAR aircraft in support of research programs. The restrictions in this section are the minimums and maximums allowable. The 14 hours duty limit is intended for short, intensive operational periods and is not to be considered as a normal work day for NCAR flight crews. Investigators must be aware of other factors that flight crews must contend with, such as the fatiguing effects of continued IFR operations, extremes of temperature, complexity of mission requirements, changes in crew work schedules, and variables that the pilot in command must consider in determining actual crew limits for any operation. during extensive programs, proper rest becomes increasingly important, and scheduled rest periods , in addition to those listed below, must be considered.

Flight duty limits for a single crew (assuming ideal working conditions).

1. Any 24-hour period 10 flight hours
2. Any consecutive 7 days 35 flight hours
3. Any 30-day period 110 flight hours
4. Consecutive working days 6 days
5. Crew duty period 14 hours
6. Minimum crew rest period 12 hours

Flight hours are determined as that time when the aircraft first moves under its own power for the purpose of flight until the moment it comes to rest at the next point of landing ("block-to-block time").

The crew duty period starts at the briefing time. or when the crew starts being "on alert," and ends when the aircraft is shut down and secured (usually landing time plus 1 hour). Days off will be scheduled at least 12 hours in advance, with the crew being relieved of all duties.

NASA ER-2:

(a) Notified at 1300L day prior to flight if ER-2 flight is requested. Detailed flight plan not required at this time, only requested takeoff time is needed.

(b) Maintenance crew and NASA contract monitor will report to hangar 3 to 4 hours prior to takeoff to begin instrument upload and maintenance preflight. Aircraft problems and instrument upload requirements will set actual report time.

(c)Approximately 3 hr.15 min. prior to takeoff, ER-2 pilot acquires takeoff/enroute/landing forecasts from USAF weather detachment at Ft.Wainwright or FAA.

(d) At 3 hours prior to takeoff, pilot briefing begins attended by Lockheed maintenance/life support, NASA monitor, and science representative from project. At this time the pilot requires final plan of science objective(s) to include desired flight track, any timing factors, checklist of science instrument operations to include procedures for cockpit indications of instrument failure(s) and designation of critical instrument(s) who's failure would make continued data collection scientifically unproductive (ie. pilot will abort mission on ground or ,if airborne, return to base). Upon receipt of above, the pilot will plan the flight and file the IFR flight plan with FAA. Any change to plan briefed at the 3 hr. pilot briefing could require replanning of the flight with accompanying takeoff delays and possible early return of the aircraft due to pilot duty limit.

(e) At 2 hours prior to takeoff, access to science instruments will cease as the crew will tow the aircraft for fueling and liquid oxygen servicing.

(f) At 1 hr. 15 min to 1 hr. prior to takeoff, pilot will begin pressure suit donning and prebreathing with 100% Oxygen. Power will be applied to the ER-2 at the engine start location so the other ER-2 pilot can begin cockpit preflight.

(g) Pilot in pressure suit is transported to aircraft around 30 minutes prior to takeoff. Engine start will occur 10-15 minutes prior to takeoff.

(h) After landing the aircraft is towed back to hangar for postflight, science data download and, if required, removal of requested science instruments.

(i) Maximum duty day for pilot is 12 hrs. which begins at arrival at weather office or hangar.

(j) Crew and pilots require 12 hrs. off duty before reporting back to work.

Night Flight Restriction: Due to remote polar ice cap area of SHEBA, ER-2 operations will require a visible horizon for flights to, near and returning from SHEBA. This should not constrain very much of the night given the time frame of the missions.

U. WA CV-580:

- Any 24-hr. period--8 flight hours
- Any Consecutive 7 Days--35 flight hours
- Any 30-day period--100 flight hours
- Consecutive working days--6 days
- Maximum Crew Duty Period--14 hours
- Minimum Crew Rest Period--12 hours

Canadian CV-580:

- 12 hours per day

5.5.2 Air Traffic Control Considerations

NCAR C-130:
Should not be a factor, but is always considered during pre-flight planning.

NASA ER-2:

U. WA CV-580:

Canadian CV-580:

To be arranged.

The fact that the aircraft will operate from different bases presents certain problems. To alleviate these problems, good communications must be maintained. The following operational constraints must be considered in planning and execution of all aircraft missions:

- research aircraft flights require approval by appropriate government agencies of countries to be overflown and/or that have control of airspace in the FIRE domain

- all flights must comply with the current ICAO regulations

- crew duty limits and rest periods will be fully observed

- aircraft operating regulations must be observed

- certain flight tracks may be restricted, necessitating revisions in the daily flight plans after filing.

5.6 Aircraft Operations Logs

Appendix K includes the aircraft operation logs, as well as the instrument operation logs for each aircraft. These logs are prepared on a daily basis to indicate aircraft, instrument and tape recorder operations and are one of several inputs for the Daily Mission Summary Report(section 3.6). The logs are prepared by the Aircraft Scientist (for the flight summary) and by the instrument Principal Investigators (for the instruments and tape recorders) at the request of the Aircraft Scientist. Table 5.6-1 indicates the logs for each aircraft and for the instruments.

Table 5.6-1. Aircraft Operations Logs Summary

Subject	**Appendix K Log Identifier**
ER-2	C
ER-2 Instruments	D
C-130	F
C-130 Instruments	G
UW CV-580	H
U WA Instruments	I
Canadian CV-580	J
Canadian CV-580 Instruments	K
Instruments Tapes	E

5.7 Safety, Flight Go/No-Go and Mission Abort Procedures

Each aircraft will have its own safety, flight go/no-go, and mission abort procedures. All investigators must follow these as required.

NCAR C-130:

-Due to insurance liability considerations, the crew must be limited to the necessary project participants. The maximum number of people on a given mission is 19.

-Flight go/no-go and flight abort criteria: This is the pilot-in-command decision, ability to safely accomplish the mission.

--Safety considerations and pre-flight training; NCAR has established a Project Safety Document that must be accomplished prior to the first research flight, A safety briefing is completed prior to each flight for anyone that has not completed the safety presentation.

--The C-130 will not fly on two consecutive days

NASA-ER-2:

NO GO: Failure of significant aircraft component, required science instrument, or weather below/worse than minimums.

NO GO: There must be an operational helicopter with a radius of action of 150 nm able to rescue any downed ER-2 pilot in the vicinity of the ship. This would mean that if there will be no helicopter for any period of time at SHEBA then the ER-2 would not be cleared to operate beyond the coast of Alaska. The ER-2 would not take-off at Fairbanks until the helicopter is fully fueled and reported ready to fly on request. Whenever the ER-2 is making flights in the vacinity of the Ship, the helicopter would be on-deck and reserved for possible ER-2 rescue duty.

Weather minimums: Ceiling as published

Visibility:

Precision Approach: > 3/4 mile or 1200 ft RVR

Non Precision: 1 Mile

Cross Wind: 15 kts

Max surface wind: 30 kts

Turbulence: No Go if reported moderate/severe or forecast severe turbulence on route

Icing: No Go if forecast or existing moderate or severe

The ER-2 may elect to fly on two consecutive days.

The ER-2 will operate within 150 km of the Ship, when making flights over the ice, in order to provide for glide to the Ship in the event of a problem requiring the pilot to bail out.

U. WA CV-580:

NOGO: Failure of significant component. Weather below minimums for take-off or landing.

GO: Anticipate that useful science can be done.

FLIGHT ABORT CRITERIA: Mechanical failure of aircraft. Unusual weather(pilot's decision).

The U WA CV-580 may elect to fly two days in succession.

Canadian CV-580:

safety

as per NRC policies

flight go/no-go criteria

GO/NO-GO criteria are based on :

- satellite overpass times
- origin of cloud systems
- formation of leads
- temperature range
- cloud physical appearance
- science objectives

flight abort criteria

- Mechanical failure of airplane
- Failure of any major instrument used for observations
- Unusual weather conditions
- If there is no significant development in the cloud for reaching the objectives specified in science plan.

5.8 Survival Training

To prepare for the event of an emergency aircraft landing on the sea ice, all persons regularly participating in aircraft flights should have previously had a survival training course. This training normally informs aircraft personnel of safety procedures regarding frostbite, polar bears, dry suits, etc. The FIRE Project Office strongly recommends such training for all personnel aboard any aircraft involved in the Arctic Cloud Experiment.

NCAR requires that all individuals who will regularly fly on the NCAR/NSF C-130 (RAF staff, scientists, etc.) will have to go through survival training. Such training is not considered as critical for those individuals who may be flying on the C-130 on a one-time basis.

The C-130 crew will also be providing a C-130 "aircraft safety briefing orientation" at the RAF prior to the departure of the aircraft for Fairbanks in May. This orientation will cover the emergency exits and procedures on the aircraft. This same orientation session is required and will be given at Fairbanks on an "as-needed" basis for others, even if flying only on a one-time basis. Such "as-needed" sessions will include an overview of the May 4 session described below.

The C-130 survival training is now tentatively scheduled for Monday, May 5, 1998, 9:00-11:00a.m., at Eielson AFB, about 20 miles south of Fairbanks. Reservations for the training must be made in advance in order to provide access to Eielson AFB. For current status and details of the training, please contact Krista Laursen.

A commercial establishment, "Learn To Return", is located in Anchorage and can be contacted about such training, if desired. The contact is Brian Hoerner at 907-563-4463.

5.9 Preparation and Turnaround Times

NCAR C-130:

-Plane preparation time for flights: Two hours unless investigators require more.

--Turn around time between flights: 15 hours/ 1 hour post flight,12 hours crew rest, and 2 hour pre-flight.

NASA ER-2:

The ER-2 crew requires 12 hours off duty before returning to duty. The aircraft and payload generally require three to four hours of prepration from initial report to takeoff.

U. WA CV-580:

Preparation: Two hours notice.

Turn-around: One hour.

Canadian CV-580:

Preparation: 1.0 to 1.3 hours

Turn-around:1.3 hours

5.10 Aircraft Operations in Vicinity of SHEBA Ship

The FIRE Arctic Cloud Experiment will have a Ship operations observer at the SHEBA Ship from April 1 until June 22. Initially, this person will be the Surface Scientist. This person will fax, telephone, radio and e-mail information from the Ship to the locations from which the FIRE.ACE aircraft will be deployed, including Fairbanks, Barrow and Inuvik. The information will be transmitted in the format indicated by Form S in Appendix K.

Because the FIRE.ACE aircraft have diverse scheduling requirements, the Daily Ship Report (DSR) will be sent at the times specified on the previous day by the Aircraft Scientists. It is expected that the DSR will be sent between 1 and 2 times a day for the period between April 1 and June 14, regardless of whether or not aircraft missions are planned.

The Fairbanks Project Office will communicate flight plans, mission objectives and ETAs of aircraft to the SHEBA site. The FIRE Ship operations observer will stand by radios during the durations of flights to consult on changing atmospheric conditions and provide general support to Aircraft Scientists and pilots. The FIRE Ship operations observer will be responsible for providing information on the status of tethered balloons, helicopters and the Ultralight before and during flights to the Aircraft Scientists. The Ship operations observer, nor any other surface-based person, will not be responsible for air traffic control around the ship--this is a pilot responsibility. It is planned that the Fairbanks Project Office will keep the Ship operations observer informed on the altitude bands in which each aircraft expects to be operating.

To insure communications capability between the Ship and the aircraft at all times, the Aircraft Scientist will contact the Ship operations observer prior to take-off to confirm MF and VHF monitoring and working frequencies and final estimate of ETA. Upon arrival in the vicinity of the Ship, the aircraft will contact the Ship on VHF to verify initiation of the flight pattern which is in the vicinity of the Ship.

Because there will not be a Surface Scientist in Fairbanks at all times, the Fairbanks Project Office will keep the Ship operations observer at the SHEBA Ship updated on the status of missions, changing requirements and quality of aircraft data sets collected.

6.0. SATELLITE OPERATIONS

6.1 Overview

Satellite observations during the field phase will be available from several different sensor systems aboard several different satellites (Table 6.1-1). Some data from those systems will be collected in real time to support mission planning and post-mission investigations. Any data which must be retrieved post-mission will need to be on a no-cost basis because there is no FIRE Project budget for this purpose. Appendix C provides more information for each satellite and its instrumentation.

Table 6.1-1. Satellites and sensors available during the FIRE III Arctic field phases (April - July 1998)

Satellite	**Sensors**	**Contact**
NOAA 12 & 14 (POES)	AVHRR HIRS/MSU	Minnis(HRPT); Wylie(GAC); Rossow(ISCCP) Wylie
DMSP F 13 DMSP F 12	SSM/I SSM/T1, T2	Rossow Rossow
RADARSAT	SAR	??
Earth Probe	TOMS	??
RESURS	SCARAB-2	Rossow
LANDSAT	TM	Wielicki

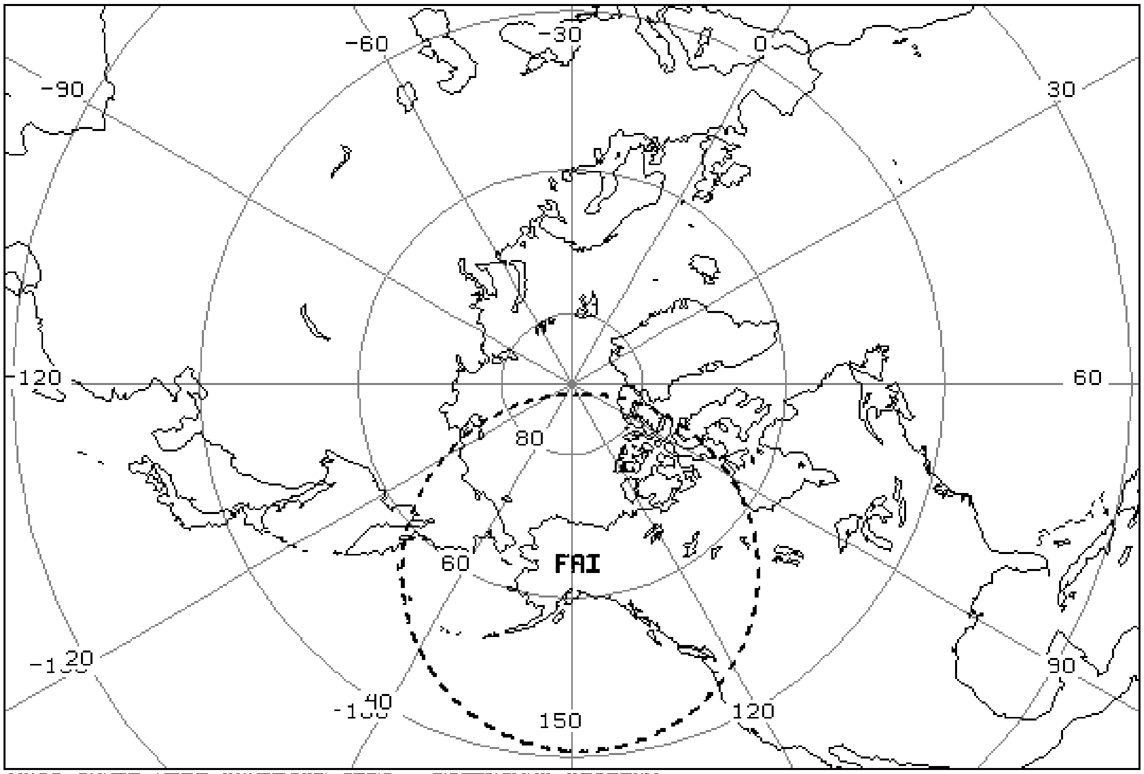
6.2 Data Collection and Analysis

The satellite data collection area and period must be adequate to ensure proper depiction of the slower evolution of the sea ice during the experimental period. Dataset coverage requirements are presented in Table 6.2-1. Table 6.2-2 indicates institutions and persons responsible for data collection. Figure 6.2-1 indicates the amount of the satellite orbit for which HRPT data can be locally received.

Table 6.2-1 Satellite Data Coverage Requirements

Satellite	Sensor	Calendar Period	Daily Time, hrs	Resolution km	Latitude	Longitude
POES	AVHRR-GAC	4/1-10/15 1998	24	4	60N-90N	0-360
POES	AVHRR-HRPT	4/1-8/10	24	1	See figure 6.2-1	
POES	HIRS2/ MSU	4/1-8/10	24	17	60N-90N	0-360
DMSP	SSM/I	4/1-8/10	24	15-45	60N-90N	0-360
DMSP	SSM/T1, T2	4/1-8/10	24	5	60N-90N	0-360
RESURS	SCARAB 2	4/1-8/10	24	40	60N-90N	0-360
RADARSAT	SAR	4/1-8/10	24		60N-90N	0-360
Earth Probe	TOMS	4/1-8/10	24		60N-90N	0-360
LANDSAT	TM	4/1-10/15				

Figure 6.2-1 HRPT Coverage Area



Appendix K includes the satellite operations logs. These logs are prepared daily by the Satellite Scientist to indicate the occurrence of overpasses at the SHEBA Ship and Barrow sites and are one of several inputs to the Daily Mission Summary Report(section 3.6). Table 6.2-2 indicates the log for each site.

Table 6.2-2. Satellite Operations Logs Summary

Subject	**Appendix K Log Identifier**
SHEBA Ship Overpasses	L
Barrow Overpasses	M

Because of the difficulties of interpreting satellite observations of the polar regions, advantage will be taken of several on-going programs to expand the data collection. First, the on-going operational weather analyses and the ISCCP cloud analysis provide a longer-term context for the SHEBA/FIRE campaign and will continue afterwards. Second, the beginning of the long-term observations at the Barrow ARM site during SHEBA/FIRE provides a link to newer satellite observations. Third, preparations for and the early part of the EOS observations and analysis bring many new tools to bear. SHEBA/FIRE will occur during a transition from today's observing system to the next generation system. By coordinating this suite of analyses with SHEBA/FIRE, we can extract more than would be possible with only the dedicated and coincident satellite collection.

There will be three types of data analysis activities: (1) special high-resolution retrievals for validation studies, (2) survey retrievals using (mostly) satellite measurements, and (3) diagnostic studies at the experiment sites combining satellite with aircraft/surface measurements. The specific data parameters and responsible investigators are listed in Table 6.2-3.

Table 6.2-3. Satellite Data Parameters and Responsible Investigators

Parameter	**Investigators**	**Sensor**
Cloud cover/fraction	Minnis; Rossow	AVHRR
Cloud cover/fraction	Wylie; Francis	HIRS
Cloud height	Wylie	HIRS
Cloud top temperature (pressure, height)	Minnis; Rossow	AVHRR
Cloud top pressure/ temperature (height)	Wylie; Francis	HIRS
Cloud IR optical thickness	Wylie	HIRS
Cloud optical thickness (visible)	Minnis; Han & Rossow	AVHRR
Cloud IR emissivity	Wylie	HIRS
Cloud IR emissivity	Minnis	AVHRR
TOA Longwave fluxes	Minnis; Rossow	AVHRR
TOA Shortwave fluxes	Rossow	AVHRR
TOA Broadband clear sky albedo	Minnis	AVHRR
TOA Broadband cloudy sky albedo	Minnis	AVHRR
Cloud particle size	Minnis; Han & Rossow	AVHRR
Cloud liquid water path	Minnis	AVHRR
Cloud liquid water path	Rossow; Curry; Lin	SSM/I
Cloud ice water path	Curry; Rossow	SSM/T2
Cloud ice water path	Minnis	AVHRR
Snowfall	Curry	SSM/T2
Atmospheric temperature	Francis	HIRS/MSU
Atmospheric temperature	??	SSM/T1
Atmospheric humidity	Francis	HIRS/MSU
Atmospheric humidity	??	SSM/T2
Ozone abundance	Operational	TOMS, HIRS
Surface albedo	Minnis; Brest & Rossow	AVHRR
Surface emissivity	Minnis	AVHRR
Surface temperature	Minnis; Brest & Rossow	AVHRR
Surface temperature	Rossow; Curry	SSM/I
Sea ice cover	Operational microwave	SSM/I
Sea ice cover & type	Operational	RADARSAT
Snow cover	Cavalieri	SSM/I
Surface Longwave fluxes	Rossow	AVHRR, HIRS
Surface Shortwave fluxes	Rossow	AVHRR, HIRS

6.2.1 Special Satellite Retrievals and Validation Studies.

Since a precise match of any two observations is very difficult to attain, validation of satellite retrievals (and surface remote sensing) will use a variety of strategies facilitated by analyses of special high-resolution satellite datasets. These special datasets will not only allow for closer, direct match-ups of measurement area and time, but will also allow for more direct comparisons of the distribution of quantities at smaller space and time scales. Comparing distribution shapes, rather than simple averages, separates biases from sampling noise. Aircraft observations will provide surveys of variations at small spatial scales (i.e. conducting area-covering flight patterns), whereas surface-based remote sensing will provide surveys of small time scale variations (i.e., long time records). The aircraft in situ measurements will be used to validate the analysis methods applied to the surface remote sensing measurements. Then distributions of quantities obtained from the combination of surface remote sensors and in situ aircraft measurements will be used to check the satellite retrievals. This includes checking the effects of sub- resolution variations of the retrieved quantities. Thus, over the whole intensive field period, a nested set of analyses will be performed, ranging from the highest resolution attained by satellites (about 1km or better)in a 1000 km region centered on the two surface sites (SHEBA ice breaker and Barrow), through intermediate resolutions cover the whole IOP region (bounded by 60-80N latitude and 90-180W longitude), up to lower resolution, but longer term coverage of the whole Arctic Basin. The PIs indicated in Table 6.1-1 are responsible for these studies.

6.2.2 Satellite Surveys

Detailed process studies, relying primarily on the surface-based and aircraft observations, are always limited by the fact that they represent a limited space and time sample of phenomena. In this case, the SHEBA ice breaker and Barrow sites will be observed for more than a year with limited-extent surface arrays about 50 km across and short (about 4-6 weeks each covering almost three months) FIRE aircraft campaigns to characterize a larger region about 200 km across. The validation studies, discussed above, serve to improve the interpretation of satellite observations. In turn, "operational", lower resolution, satellite analyses, augmented by some special, higher resolution, experimental analyses, will cover the whole Arctic region (poleward of 60N latitude) for several years. Improved interpretation of these survey datasets will provide the statistical ensemble of cases needed to generalize the detailed field campaign results. The PIs indicated in Table 6.1-1 are responsible for these surveys.

6.2.3 Diagnostic Studies

Many quantities are retrieved directly from satellite measurements of spectral radiances; however, total radiative fluxes and radiation budgets, in particular, are inferred more indirectly from these retrievals. Although these approaches may prove reasonably accurate when based primarily on satellite observations (FIRE has an objective to show this or indicate needed improvements), the combination of in situ and remote sensing at the surface sites and from the aircraft over the sites will also be used to supplement this type of satellite analysis in more detailed diagnostic studies at the sites. In other words, the best analysis of energy budgets at the surface sites is likely to result from the use of maximum information obtained from all available measurements, including those from the satellites. Table 6.2.3-1 identifies the planned diagnostic study and the persons involved.

Table 6.2.3-1 Diagnostic Studies

Study Designation	Responsible Person	Parameters Included
Arctic Radiation Budget	Rossow & Zhang	TOA & surface, SW & LW, upwelling & downwelling radiative fluxes

6.3 Support for Mission Planning

During the field phase of FIRE, some satellite observations will be collected in real time to support mission planning. Table 6.3-1 indicates the satellites and instruments, the data collection facility, uses, and the investigators responsible for conducting field analyses. Pat Minnis will produce, in near real time at Ft. Wainwright, loops of images of a variety of satellite-inferred data parameters for locations over the SHEBA Ship, Barrow and Fairbanks. GIF images will be available at Fairbanks and digital data will be available at Langley.

Table 6.3-2 indicates the persons responsible for providing satellite overpass predictions for the SHEBA Ship and Barrow. Appendix P provides recently prepared satellite overpass predictions which will be representative, but should be revised within a month of actual use in order to provide more accurate overpass times. Actually, Appendix Q provides predictions of time of closest overpass. The satellite viewing zenith angle should be less than 60 degrees to the target surface in order to be considered to provide valid measurements. While there is not a requirement that the satellite closest point of approach to the Ship be at the same time the plane is overhead, there is a desire to know when the satellite closest point of approach is nearest the Ship and the airplane track.

Table 6.3-1.   Mission planning satellite operations

Instrument/Satellite	Facility	Use	Investigator
AVHRR/NOAA and SSM/I-DMSP	Fairbanks Weather Service Office	Synoptic forecast, aircraft vectoring to cloud systems	Wylie; Minnis
SAR/RADARSAT	SAR facility	Sea ice cover	??

Table 6.3-2. Satellite Overpass Predictions

Satellite	Responsible Person	E-mail address
NOAA 12 & 14	Louis Nguyen	louis@angler.larc.nasa.gov
DMSP F12 & F13	Louis Nguyen	louis@angler.larc.nasa.gov
RADARSAT	TBD	
Earth Probe/TOMS	TBD	
RESURS	TBD	
LANDSAT	TBD	

6.4 Surface-based Observations in Support of Satellite Data Analysis

Major objectives of the satellite analyses are to measure the properties of the surface sea ice, atmosphere and clouds with sufficient accuracy to determine the top-of-atmosphere, surface and in-atmosphere radiative fluxes. If the mesoscale variations of these quantities are resolved, then these data will also be used to study the processes that affect the evolution of the polar climate, especially those that couple the ocean-sea ice-atmosphere and cause feedbacks on climate change. FIRE focuses especially on cloud and radiation processes. Direct support of the satellite measurements comes from surface measurements of the same quantities (see Table 6.2-3) and from measurements of other quantities that affect the interpretation of the satellite data (especially cloud vertical structure, smaller scale variations, and cloud microphysics), but cannot be measured by satellites. Direct measurements of surface properties are planned over small areas (about 10 - 50 km) at the SHEBA ice breaker and at Barrow, including characteristics of the snow and ice, particularly their spectral albedo and skin temperatures. Meteorology, including both near-surface and upper air measurements of temperature, humidity, pressure, and winds, are needed. Surface remote sensing of cloud properties (cloud base and top, phase, water path) from the lidar-radar combination are especially important. An array of surface radiometers to measure the surface radiative fluxes over a 50 km domain will be needed to verify the satellite-based determinations of the surface radiation budget. Since the calculations of the radiative fluxes include more detailed input and output, such as the microphysical properties of the clouds (particle shape and size distributions), aerosol characteristics, and the spectral dependence of the radiative fluxes, additional measurements of these quantities will constrain possible sources of error in the analysis. Moreover, to complete the process studies also requires retrieval of additional cloud and sea ice properties, other than those that affect the radiation directly.

Key surface instrumentation includes: surface shortwave(some instruments should separate direct and diffuse radiation; spectral discrimination on some instrumnents would also help characterize aerosols) and longwave flux radiometer array covering an area about 50 km across, infrared spectrometer, radiometric determination of surface albedo and skin temperature around surface sites, rawinsondes and surface temperature/humidity/wind measurements, cloud radar and lidar. Complete time records from all surface measurements are required (time resolution should be better than 10 minutes for radiation and at least 3-hr for atmospheric and cloud properties).

6.5 Aircraft-based Observations in Support of Satellite Data Analysis

Aircraft measurements support satellite analyses in three ways: (1) providing calibration transfer amongst all the radiation measuring instruments, satellite as well as surface, (2) providing in situ and vertical profile measurements of cloud properties and radiative fluxes, and (3) surveying small-scale spatial variations of clouds and radiation over a larger domain than possible from the surface. This section describes several aircraft observation strategies designed for these purposes; most of these can be accomplished while piggy-backing on missions with other objectives. Table 6.5-1 summarizes the various flight plans that are described in more detail in Section 5.4.

Table 6.5-1 Summary of Aircraft Flight Plans

Section No.	Description	Aircraft	Satellites
5.4.1	Cloudy Boundary Layer	C-130	
5.4.2	Clear Stable Boundary Layer	C-130; Ultralight	
5.4.3	Clear Sky	ER-2; C-130	
5.4.4	Leads	Can CV-580; C-130	

5.4.5	Surface Sensor Validation	ER-2; C-130; Can CV-580; U WA CV-580	
5.4.6	Surface Mapping	ER-2	yes
5.4.7	Cloud/Radiation	C-130	
5.4.8	Cloud Characterization	ER-2; U WA CV-580	
5.4.9	Arctic Haze	U WA CV-580; Can CV-580	
5.4.10	ER-2/UW coord. flights	ER-2; C-130; U WA CV-580; Can CV-580	yes
5.4.11	Aircraft/Satellite Intercomparison	ER-2; C-130; Can CV-580; U WA CV-580	yes
5.4.12	Convair/Surface Intercomparison	U WA CV-580; Can CV-580	
5.4.13	SHEBA Aircraft	Ultralight, Helicopter; Twin Otter	

6.5.1 Satellite/Aircraft Radiometer Comparison Missions

Calibration of satellite, surface and aircraft radiometers is critical to the success of FIRE III Arctic experiment, especially for shortwave(i.e. solar)radiance measurements. The strategy for the inter-calibration of the satellite and aircraft imaging radiometers is similar to the FIRE II Cirrus experiment. Special missions will be flown to intercalibrate the ER-2, Convairs, C-130 and satellite radiometers. In addition, missions should be conducted over the SHEBA and Barrow sites. The ER-2 MODIS Airborne Simulator (MAS) radiometer will be used as the transfer standard. Appendix D.2.2 shows the spectral bandpasses for the shortwave channels on MAS, which have been selected to optimize intercalibration of current satellite radiometers (mainly AVHRR) and provide a preview of MODIS data on future EOS spacecraft. This requires coordinated ER-2 flights with the other aircraft and during satellite overpasses, so that the MAS has similar viewing geometry to the satellite radiometers. Predictions of satellite overpass and control of the ER-2 flight path (plus or minus 5 minutes) should allow matching of viewing angles to within 2-5 degrees. Intercalibration data should be collected over thick cloud layers and clear, open ocean, if the opportunity arises, and within 15 degrees (preferred, 30 degrees acceptable) of nadir view. Cloud height information from the ER-2 lidar is desirable, as well as wind information, if available. The analysis procedure follows that described in Wielicki et al. (1990). Such intercalibration flights should be conducted once near the beginning and once near the end of the experimental period, requiring about 4.5 flight hours. The actual time devoted to the calibration measurements is less than 15 minutes per flight. Since the satellite ground tracks are nearly north-south oriented, the ER-2 flight track along this direction will usually be perpendicular to the wind direction as required for other experiment objectives.

6.5.2 In situ and Vertical Profile Measurements

Key objectives for aircraft missions are to (1) make in situ measurements of profiles of cloud microphysical and atmospheric properties, (2) characterize the smaller scale variations of cloud properties in both the horizontal and vertical, and (3) characterize the smaller scale variations of radiative fluxes, particularly in the vertical. Vertical profiling missions should be conducted over the surface sites to compare with surface remote sensing results. Both vertical profiling and horizontal runs should be coordinated with satellite overpasses, where possible, particularly when calibration is also an objective. The purpose of these measurements is to verify the analyses of both surface and satellite remote sensing; therefore, measurements should be made of quantities retrieved from the remote sensors, including radiative fluxes, as well as in situ determinations of the microphysical properties of the clouds (and aerosols, if possible).

6.5.3 Survey of Small-scale Variability

An additional important role of the aircraft observations complements the surface-based measurements by extending the survey of variations of the atmosphere, especially clouds, and surface to a larger spatial domain. While the surface observations will provide both high time resolution and a long time record, as well as key information about vertical structure, the aircraft are needed to complete the description of the three-dimensional variations by extending the SHEBA ice breaker array to a domain of about 250 km. The measurements should characterize the small-scale horizontal inhomogeneities of the atmosphere, clouds, surface and radiation fields. This extension allows for comparisons with the satellite observations over a range of scales from about 1 km to 250 km that will better separate sampling effects from measurement errors.

7.0 INSTRUMENTATION CALIBRATION

In an attempt to minimize and understand differences between similiar measurement capabilities, the calibration program will include flight instrument calibration before and after the mission, intercomparison to reference measurements during the experiment and documentation of these efforts. This documentation, described in section 7.1, is to be submitted to the archive along with the instrument science measurements.

7.1 Calibration Documentation

As part of the quality assurance procedure for the SHEBA/FIRE experiment, it is requested that operators of instrumentation supply the following information for inclusion in the data archives:

a) History and description of instrumentation calibration prior to deployment in S/F.

b) Real-time log of calibrations, performance, repairs, modifications, and cleanings of instrumentation during S/F experiment; and name of operator and affiliation.

c) Error estimate of measurement.

d) Raw data produced by instrumentation whenever possible.

e) Detailed procedure or algorithm used to convert raw data to value-added data.

f) Justification for not recording data with common data logger.

g) Post S/F calibration and probe evaluation, if available.

7.2 Radiation Instrumentation Calibration

7.2.1 Broadband radiometers (surface and aircraft)

All such instruments at the SHEBA Ship and ARM (Barrow) sites have been calibrated at the Boulder World Calibration facility before going to the field. They will be returned to Boulder for a postcampaign calibration. Aircraft instruments are to be calibrated before and after the FIRE III Arctic campaigns at Boulder or at either of the Ames or Goddard calibration facilities. Canadian instruments will be calibrated at the Canadian World Calibration facility. All FIRE instrument investigators are to deliver to the FIRE data archives complete instrument documentation (spectral and angular responses, sensitivity and noise specifications) and the results of the before and after calibrations, plus any in-field calibration results. All calibrations must be traceable to NIST standards.

7.2.2 Spectral sensors

Spectral radiation instruments are more difficult to calibrate in terms of total energy received; however, these instruments will be operated at the Goddard calibration facility (or at Ames were a related integrating sphere is available) to provide “side-by-side” measurements with the MAS instrument that will fly on the ER-2. Complete instrument documentation and the results of all calibrations will be delivered to the FIRE data archives as part of the instrument datasets.

7.2.3 Aircraft-to-surface

To facilitate cross-comparisons of aircraft and surface radiometers (broadband and spectral), all aircraft will operate over the SHEBA Ship and/or ARM (Barrow) sites under clear sky conditions at least once during their campaigns. Special datasets from the surface and aircraft instruments during these flights will be prepared by the instrument investigators as a high priority and delivered to the FIRE data archives as part of the documentation of these instruments.

7.2.4 Aircraft-to-satellite

Because of the extensive areal coverage and comprehensive spectral coverage and resolution of the suite of instruments flying on the ER-2, comparisons of observations by the ER-2 under both clear and cloudy conditions at both the SHEBA Ship and ARM (Barrow) sites will be compared with satellite observations to provide a cross-calibration. Special datasets from the ER-2 and satellite (especially highest resolution samples) instruments will be prepared by the instrument investigators as a high priority and delivered to the FIRE data archives as part of the documentation of these instruments.

7.3 Microphysics Instrumentation Calibration

There presently exists no method for intercomparing/calibrating, prior to and during SHEBA/FIRE, the same and similar microphysics probes carried on the three aircraft (NCAR C-130, Canadian CV-580 and U.Wash. CV-580). Near simultaneous in-cloud measurements by the aircraft are considered potentially hazardous, and have not yielded definitive results in the past. The reliability of extrapolating in time and space the microphysical measurements made by each of the three aircraft must therefore rely on less direct means that are recommended as follows:

a. All probe users are responsible for calibrating their own probes according to the manufacturer's guidelines.

b. For droplet-measuring probes (e.g., FSSP, King, JW, PVM) that are deployed on more than one aircraft, the users will chose and use i) the same correction algorithm if feasible, and ii) the same droplet-size response characteristics, especially in the response roll-off regions.

c. Users of drizzle/droplet OAPs will specify and agree, in the most consistent way possible, on the response of these probes.

d. The PVM is used as a reference probe for facilitating intercomparisons (LWC, dN/dr, Re) between other cloud-droplet microphysics probes on the three aircaft. This recommendation has the following rationale: i) each aircaft will carry a PVM; ii) the calibration and response of the three PVM will be checked simultaneously in a cloud chamber prior to the experiment; and iii) field calibration checks, including checks during flight, are practical and should provide evidence that the stability of the PVMs is maintained.

7.3.1 NCAR Microphysical Sensor Calibration Plan

- **Calibration**

<u>Frequencv</u>
Before and after every project
At least once during a project
More than once when needed
(QA or Environment driven)

<u>Scattering Probe Methodology</u>
(PCASP, FSSP-300; MASP, FSSP-100)
glass beads/PSLs
Optical alignment

Sample Volume Measurement
Response Time Measurement

Optical Array Probe Methodology
(260-X, 2D-C, 2D-P)
Spinning Disk
In-Can Alignment

Hot Wire Probe Methodology
Analog Channel Calibration

Particle Volume Monitor
Manufacturer's Calibration Disk
(Other methods being studied)

- **Quality Assurance**

On-Site Expertise
Consistency with Environmental Conditions
In-flight quick-look
2D Image Examination

Inter-comparisons between Sensors
LWC Redundancy
Overlapping Size Ranges

Housekeeping/Auxiliary Parameters
End diode voltages
Average transit times
Velocity Reject/DOF Ratios
2D Buffer Times
Clear air noise/offsets
PCASP Flowrate
MASP TAS
MASP Quad Detectors

7.4 Aircraft Microwave Instrumentation Calibration

Calibration of microwave radiometers in terms of total energy received can be done against electrical standards. The two aircraft instruments will be calibrated at their respective aircraft facilities. Both instruments will be flown at least once over the SHEBA site during clear (over thin cloud overcast) conditions near the time of DMSP satellite overpass to provide a cross-comparison with satellite microwave observations. Complete instrument documentation and the results of before, after and in-field calibrations will be delivered to the FIRE data archives as part of the instrument datasets.

8.0 DATA SETS AND MODELING OPERATIONS

All observations and models need to relate to physical processes, remote sensing, or climate modeling. The following paragraphs describe the datasets and models required to address the science questions related to the experiment objectives. See Appendix G for compilations of data parameters to be provided by the instrumentation from all platforms.

8.1 Arctic Climate Processes and Modeling Datasets

Achieving the overall goals of FIRE III requires that the dataset be easy for modelers to use. Few modelers will want to wade through the entire dataset, synthesizing data from multiple investigators that involve multiple platforms and time and space scales, to assemble a dataset that will allow the modeler to test parameterizations, hypotheses, etc. To make the dataset attractive and easy to use by modelers, subsets of the data must be packaged in a way, with the datasets designed ab initio to act as input files to the models and as validation.

In developing integrated datasets, we will focus on datasets that we anticipate will be used by a large number of investigators, including those from SHEBA, ARM, FIRE, and the international modeling communities. Two of these datasets focus on the coupled air/sea/ice system, and are called the Instantaneous Radiative Flux dataset and the Single-Column Model dataset. The other datasets are targeted at large-eddy simulations of the atmospheric layers. These datasets will be constructed collaboratively by FIRE, ARM, and SHEBA investigators. The lead person for the development of each dataset is indicated in Table 8.1-1.

Table 8.1-1 Dataset Development Leads

Dataset Name	**Lead for Development**
Instantaneous Radiative Flux	Knut Stamnes
Single-Column	Steven Krueger
Large-eddy Simulation	Judy Curry

8.1.1 Instantaneous Radiative Flux Dataset

The concept of the Instantaneous Radiative Flux (IRF) experiment originated with the DOE ARM program. The idea is to make near-instantaneous measurements of the radiation field and the atmospheric parameters that determine the radiation field (e.g. clouds, temperature, trace gas concentration). Nearly instantaneous measurements are required, since the entire atmospheric radiation field adjusts almost instantaneously to changes in atmospheric optical and thermal properties. SHEBA plans to extend the general concept of the IRF experiment to include the sea ice and upper ocean.

The basic idea behind the IRF dataset is to measure all of the input (I) data that would be required for input into radiative transfer models that are designed to simulate the radiative energy transport through the atmosphere-sea ice-ocean column, and the evaluation (E) data that would be required to test the models' ability to reproduce the measured radiative fluxes and radiances throughout the column. The rationale behind this approach is that such models can subsequently be used with some confidence as a basis for parameterizations required to compute reliable radiative heating/cooling rates in a single grid cell of a GCM.

The following variables will he included in the IRF dataset:

(1) (I,E) top-of-atmosphere radiation fluxes (ER-2, satellite)
(2) (I) ozone profiles (satellite, climatology)
(3) (I) temperature and humidity profiles (radiosonde, tethered balloon)
(4) (I) aerosol profiles (1idar, aircraft)
(5) (I) profiles of cloud phase, particle size distribution, ice and liquid water content (cloud radar and lidar, tethered balloon, aircraft)
(6) (I) profiles of cloud fraction and the horizontal variance of condensed water content (aircraft)
(7) (E) vertical profiles of atmospheric radiation fluxes (aircraft, tethered balloon)
(8) (I) surface temperature (surface measurements, aircraft)
(9) (I,E) surface albedo (surface measurements; aircraft)
(10) (I) statistics of ice surface characteristics (aircraft)
(11) (E) surface radiation fluxes (surface radiometers, aircraft)
(12) (I) snow depth, density, water content, grain size, particulates (surface-based measurements)
(13) (I) ice density, salinity, brine and air bubble content for different ice thickness (surface-based measurements)
(14) (I,E) horizontal distribution of cloud properties (ER-2, satellite)

Many of the input (I) variables are not prognostic variables in climate models, and therefore are specified either from climatological values or implicitly through the parameterization itself. One of the tasks of SHEBA and FIRE Experiments is to define the smallest set of variables that climate models must furnish to their radiation submodels to guarantee useful radiation predictions.

The most complete IRF cases can be assembled for periods when research aircraft is available. We will include in the IRF dataset with a sufficient number of cases to span the range of temperatures, solar zenith angles, cloud and surface characteristics that occur over the annual cycle. We anticipate including about 10-20 cases representing the following situations:

- clear sky: winter, spring, summer melt season
- diamond dust: winter, spring
- mixed phase cloud: spring
- liquid boundary layer cloud: spring, summer
- multiple cloud layers: spring, summer

8.1.2 Single-column Dataset

Improved parameterizations of physical processes will be developed using observations obtained at the ice camp and from aircraft. To be useful in a coupled climate model, these parameterizations must be evaluated against observations in a systematic way in the context of models of the coupled atmosphere and ocean. The SCM is a framework for testing key process models and parameterizations in a GCM by extracting a single vertical array of cells from the model and operating the model in what is called single-column model. Observations are used to specify what is going on in “neighboring columns,” and observations may or may not also be used to specify tendencies due to some parameterized processes, other than those being tested.

A horizontal domain of approximately 60- 100 km will define the horizontal extent of the grid cell, with the upper cell boundary at the atmospheric tropopause and the lower boundary below the ocean mixed layer. Most of the data collected in the combined SHEBA/ARM/FIRE field experiment will be incorporated into the single-column dataset in some way. To operate models in SCM mode, it is necessary to specify the initial values of the prognostic variables within the model cell. It is also necessary to provide the boundary conditions for the column and their time evolution. The GCM parameterizations are then tested by comparing measured and modeled evolution of the prognostic and other variables. Observations serve to determine the boundary and initial conditions of the prognostic variables and to track their temporal evolution for comparison with model predictions.

The SCM dataset will include parameters that are required for model initialization (I), forcing at the boundaries (F), and evaluation (E). Since different model configurations will require different subsets of the data for initialization, testing, and forcing, the data set will be configured so that the following parameters will be included. The general enumeration of the variables proceeds from the top of the atmosphere down to the pycnocline. We will attempt to provide a single-column dataset for the entire SHEBA year, although there will be SCM IOPs during periods when aircraft are available and enhanced observations can be provided.

(15) (I,E) top-of-the-atmosphere radiative fluxes (satellite; NASA ER-2)
(16) (I,E) horizontal distribution of cloud properties (satellites)
(17) (I,E) vertical profiles of atmospheric temperature, humidity, wind velocity (tethersonde up to 1 km; rawinsonde up to 15 km)
(18) (I, E) vertical profiles of cloud and aerosol properties (cloud lidar/radar; tethered balloon; aircraft)
(19) (E) vertical profile of radiative fluxes (tethered balloon; aircraft)
(20) (E) vertical profiles of variances and covariances of temperature, humidity, and wind velocity in the atmospheric boundary layer (aircraft; cloud radar)
(21) (F) vertical profiles of horizontal advection of atmospheric temperature and humidity and large-scale divergence (NWP analyses; aircraft)
(22) (F, E) aerially-averaged components of surface turbulent fluxes, radiation fluxes, and precipitation (surface obs; aircraft)
(23) (F, E) statistics of the ice thickness distribution, lead fraction, snow cover, melt pond properties (sonar; SAR; aircraft)

----------------Additional SHEBA observations for coupled models--------------------------

(24) (I, E) temperature profiles in ice of different thickness (thermistor chains)
(25) (E) Ice mass balance for different ice thickness and snow depths
(26) (F) ice mass divergence (buoys; SAR)
(27) (F, E) areal-averaged components of the ice/ocean interfacial fluxes of heat, salt, momentum and radiation (ADCP, TIC)
(28) (I, E) vertical profiles of temperature, salinity and currents in the upper ocean (CTD, ADCP)
(29) (I,E) turbulent flux profiles of heat, momentum, and salt in the upper ocean (TIC)
(30) (F) horizontal advection of heat and salt in the upper ocean (mesoscale array of CTD)

Construction of the SCM integrated dataset will require a major research effort by most of the combined SHEBA/ARM/FIRE Science Team. Since many of the parameters in the list above require major research efforts in themselves to analyze, construction of the SCM dataset will be completed in SHEBA Phase III. Oversight of SCM activities will be coordinated by Krueger for the atmosphere.

8.1.3 Large-eddy Simulation Dataset

The observations required to initialize, force, and evaluate large-eddy simulations (LES) are essentially the same as those required by SCMs. The primary difference is that spatial inhomogenieties at the ice-ocean-atmosphere interfaces can be resolved to a much greater degree by LES models than by SCMs. In a LES, these inhomogenieties are specified as part of the initial conditions, and in many cases as part of the boundary forcing as well.

In collaboration with FIRE III, Krueger, Duynkerke and Curry will assemble a complete dataset for each of several different cloudy atmospheric boundary layer situations for use by SHEBA and FIRE III investigators and in the GCSS (GEWEX Cloud System Study) boundary layer cloud and arctic cloud model intercomparisons (Browning et al., 1994). This dataset will be obtained from surface and aircraft observations, and will also use satellite and NWP analyses. This dataset will include:

(31) (I,F[wind only],E) mean profiles of temperature, humidity, winds, cloud water content and cloud phase and particle size distribution (ice camp)
(32) (F) vertical profiles of horizontal advection of atmospheric temperature, humidity, and hydrometeors, and large—scale atmospheric divergence (NWP)
(33) (E) profiles of radiative fluxes (aircraft)
(34) (E) fluxes and covariances of velocity, temperature, and humidity quantities (aircraft)
(35) (I,F,E) surface characteristics and fluxes (ice camp, aircraft)

These quantities will be used to initialize, force, and evaluate models of the cloudy atmospheric boundary layer. A particular focus of both FIRE and SHEBA is the atmospheric convective boundary layer in the presence of a lead. FIRE will provide additional analyses of the summer multi-layered cloudy boundary layer and the springtime mixed-phase cloudy boundary layer.

8.2 Arctic Measurement Validation Dataset

The purpose of the Arctic Measurement Validation Data Set will be to provide carefully analyzed data sets from sensors which require validation and cross calibration. This activity will have two separate components: 1) validation of retrieved properties from surface sensors with in-situ sensors on balloons or aircraft and 2) validation of retrieved products from satellite based sensors using appropriately time averaged surface-based measurements.

8.2.1 Validation of Surface Sensors with In-Situ Aircraft and Balloon Measurements

Surface based remote sensors when used in combination can provide a number of retrieved cloud and aerosol properties which impact the radiative properties of the atmosphere. Typically, these sensors operate continuously throughout the depth of the atmosphere which provides obvious advantages over episodic measurements made by airborne sensors. Conversely, because many of the parameters provided by the surface sensors are retrieved properties (i.e. inferred from a combination of theory and direct measurements rather than measured directly) it is crucial that these measurements be validated using in-situ sensors that can be provided by tethered balloons or airbourne sensors. The airborne measurements of cloud properties are useful for validation of surface sensors only if the aircraft make a sufficient number of passes over or near the surface site so that a reasonable number of samples for comparison are available. While this might appear to be an obvious constraint, in fact previous projects have indicated that coordinated surface aircraft measurements typically are difficult to obtain, and there is often an irresistable temptation for aircraft to leave the immediate area of the surface sensors and sample tempting looking clouds at some distance. Because of the complexity of the expected cloud types (multiple layers, mixed phase) the aircraft measurement will be indespensible in determining the conditions under which the surface-based retreivals will be valid. Therefore, a maximum number of near passes at a variety of levels will be necessary to achieve the validation objective.

8.2.2 Validation of Satellite based sensors with Surface Measurements

For validation of satellite-based retrieval techniques an important component is to determine the autocorrelation length scales. For example, given a 5 m/s wind speed, 24 hours of data corresponds to 430 km of advection distance. Autocorrelation scales for cloud layering may easily be 1000 km and many realizations of this scale will be necessary to make statistical comparisons between surface and satellite measurements of cloud properties on the order of 1 day * (1000/430) * 30 = 2 months. Since these time scales will likely exceed the period of the FIRE III IOP, retrieved surface products over the length of the SHEBA program will be highly desirable. These products will be produced and made available to the FIRE III community in cooperation with the NASA/MTPE CERES program.

8.2.3 Measurement Variables for the Validation Data Set

During the FIRE III aircraft overflights, surface based data sets will be analyzed especially carefully. In addition to automated retrieval products that will be produced for the duration of the SHEBA program, the data sets collected during the IOP will be analyzed with the objective of providing some intensive case study analysis where an optimum combination of radar, lidar, radiometric, ceilometer techniques have been utilized to provide synergistic description of the atmosphere in the column over the SHEBA site. Key parameters will be:

(36) Particle Phase
(37) Particle Size
(38) Particle Concentration
(39) Particle habits
(40) Liquid water content
(41) Ice mass content
(42) Particle Fall Speeds
(43) Layer Cloud Fraction
(44) Cloud Boundary Heights
(45) Number of Cloud Layers
(46) Aerosol Backscatter
(47) Identification of Mixed Phase Layers
(48) Identification of discrete liquid water layers
(49) Temperature Profiles

8.3 Operational Models

Operational numerical weather prediction models will play a crucial role in FIRE. The ECMWF and NCEP operational models will be used to provide forecasts to aid in planning the aircraft campaigns. Assimilation of FIRE/SHEBA/ARM data during the experiment will improve the NWP analyses and predictions. The NWP analyses will also be used to define the synoptic scale variability in the experimental region.

ECMWF and NCEP have a six-hourly data simulation cycle. Soundings taken at the ice station will be put onto the GTS as rapidly as possible so that they can be assimilated into the models.

Appendix M contains the Agreement between ECMWF and NASA.

Horizontal grid spacing for the NCEP models ranges from 15 to 75 km in the horizontal. At present daily SSM/I sea ice concentrations are used as the lower boundary condition. An operational sea ice forecast capability is being developed, which should be ready in time for SHEBA. The sea ice model will eventually used to provide the bottom boundary condition for the atmospheric model, which will include ice thickness variations, although this is unlikely to be ready in time for SHEBA. NCEP can provide complete analysis products to SHEBA. No special SHEBA subset of the NCEP data is planned at this time. Most of the output from the operational models can be found at the NOAA Information Center web page indicated in Table 9.4-1 or ftp://nic.fb4.noaa.gov/pub/.

- Contact: Robert Grumbine, rmg3@polar.wwb.noaa.gov; Ken Campana

The ECMWF model has approximately a 60 km horizontal resolution. 4DVAR will become operational by mid 97, which is expected to provide a quantum leap in analysis accuracy and forecast skill. Special services that will be provided to SHEBA through its collaboration with FIRE and ARM:

1. Real time forecasts. Can use any observations that are assimilable and reach GTS, including ship buoys, radiosondes, aircraft winds, RASS.
2. Mask diagnostics. For limited regions, can archive full description of physical and diabatic tendencies. This can be done for several fixed grid points. This will be done for the SHEBA ice camp by updating the position of the ice camp on a weekly basis.
3. Conventional analysis fields at standard pressure levels. Reanalysis can be done for a month or two, to take advantage of data that didn't initially make it onto the GTS. This may be proposed for main FIRE IOP. ECMWP has had many productive interactions with past field experiments, and the have used results from field experiments to improve model parameterizations.

As a member of the FIRE Science Team, ECMWF is generously providing hourly forecast model output for the SHEBA column to the FIRE/SHEBA Science Team, including many non-standard fields (such as radiative fluxes, surface temperature and winds, and vertical distributions of cloud and ice water and precipitation) at the full 31-level vertical resolution of the model. The model output is taken from 12-35 hour forecasts of the ECMWF operational model, and since 22 Oct 1997 has been sent daily to the University of Washington. The twice-daily soundings and routine surface observations of pressure, wind, temperature, humidity are being assimilated into the model to help initialize each daily forecast cycle. However, other fields are generated by the model itself with little direct constraint from SHEBA observations, and MUST NOT BE REGARDED AS OBSERVATIONS. Please see the ECMWF URL in section 9.5 for more information about model output.

- Contact: Christian Jakob, Martin Miller

The AES back-trajectory model uses the analysis fields of the AES operational model at several past time intervals to calculate where the air came from that now appears over any particular spot. The trajectories are calculated at specific pressure intervals and assume the air moves along a constant pressure surface. The back trajectory model can also run in a predictive mode, i. e. you can predict what air mass will be over a particular spot in the next few days using the operational model forecasts instead of the analysis field. Trajectories are available for whatever pressure levels you specify, usually 950, 850, 700 and 500 mb. The model can be set up to run in real time at the Canadian operational centre (CMC) and the ship location will be specified as one spot. This would provide a good idea if aerosols and trace gases from particular source regions are being advected over the ship. Such a model has been used for many atmospheric chemistry field projects and it was found that it works very well in a real time predictive mode. Results from the model will be available via fax or a web page for use in flight operations planning.

- Contact: George Isaac; 416-739-4605; george.isaac@ec.gc.ca